UM1052
User manual

STM32F103xx or STM32F100xx PMSM single/dual FOC SDK v3.0

Introduction

This manual describes the Motor Control Software Development Kit (generically called software library) designed for and to be used with STM32F103xx or STM32F100xx microcontrollers (STM32F103xx also called STM32 performance line, STM32F100xx also called STM32 value line). The software library implements the Field Oriented Control (FOC) drive of 3-phase Permanent Magnet Synchronous Motors (PMSM), both Surface Mounted (SM-PMSM) and Internal (I-PMSM).

The control of an AC induction motor equipped with encoder or tacho generator is described in the UM0483 user manual.

The STM32F family of 32-bit Flash microcontrollers is based on the breakthrough ARM Cortex™-M3 core, specifically developed for embedded applications. These microcontrollers combine high performance with first-class peripherals that make it suitable for performing both permanent-magnet and AC induction motor FOC.

The PMSM FOC library can be used to quickly evaluate ST microcontrollers and complete ST application platforms, as well as to save time when developing Motor Control algorithms to be run on ST microcontrollers. This PMSM FOC library is written in C language, and implements the core Motor Control algorithms (reference frame transformations, currents regulation, speed regulation, space-vector modulation, energy efficiency optimizations) as well as sensors reading/decoding algorithms (three shunts, ST-patented single DC link shunt, isolated current sensors, incremental encoder, hall sensors) and a sensorless algorithm for rotor position reconstruction.

When deployed with STM32F103xx High-Density / XL-Density devices (Flash memory density between 256 and 512 Kbytes / 768 Kbytes and 1 Mbyte), the PMSM FOC library enables simultaneous dual FOC of two different motors. The library can be customized to suit user application parameters (motor, sensors, power stage, control stage, pin-out assignment) and provides a ready-to-use Application Programming Interface (API).

A user project has been implemented to demonstrate how to interact with the Motor Control API. The project provides an LCD User Interface and a USART User Interface, represents a convenient real-time fine-tuning and remote control tool for the motor control application.

A PC Graphical User Interface (GUI), the ST Motor Control Workbench, allows complete and easy customization of the PMSM FOC library. In conjunction with the STM3210B-MCKIT motor control starter kit, a PMSM motor can be made to run in a very short time using default parameters.

Basic knowledge of C programming, C++ programming (for customizing the LCD User Interface), PM motor drives and power inverter hardware is necessary for using the software library. In-depth know-how of STM32F103xx or STM32F100x peripherals/functions is only required for customizing existing modules and for adding new ones for a complete application development.

Contents

1 MC software development kit architecture 10

2 Documentation architecture 13

2.1 Where to find the information you need 13

2.2 Related documents 14

3 Overview of the FOC and other implemented algorithms 15

3.1 Introduction to the PMSM FOC drive 15

3.2 PM motor structures 17

3.3 PMSM fundamental equations 18

3.3.1 SM-PMSM field-oriented control (FOC) 19

3.4 PMSM maximum torque per ampere (MTPA) control 20

3.5 Feed-forward current regulation 22

3.6 Flux-weakening control 23

3.7 PID regulator theoretical background 25

3.7.1 Regulator sampling time setting 25

3.8 A priori determination of flux and torque current PI gains 26

3.9 Space vector PWM implementation 29

3.10 Detailed explanation about reference frame transformations 30

3.10.1 Circle limitation 32

4 Current sampling 34

4.1 Current sampling in three shunt topology 34

4.1.1 Tuning delay parameters and sampling stator currents in three shunt resistor topology 36

4.2 Current sampling in single-shunt topology 40

4.2.1 Definition of the noise parameter and boundary zone 43

4.3 Current sampling in isolated current sensor topology 46

5 Rotor position / speed feedback 48

5.1 The sensorless algorithm 48

5.1.1 A priori determination of state observer gains 49

5.2 Hall sensor feedback processing 51

5.2.1 Speed measurement implementation 51
5.2.2 Electrical angle extrapolation implementation 53
5.2.3 Setting up the system when using Hall-effect sensors 54
5.3 Encoder sensor feedback processing 56
5.3.1 Setting up the system when using an encoder 57

6 Working environment 58
6.1 Motor control workspace 59
6.2 MC SDK customization process 61
6.3 Motor control library project (confidential distribution) 62
6.4 Motor control application project 63
6.5 User project 64
6.6 LCD UI project 66

7 MC application programming interface (API) 70
7.1 MCInterfaceClass 71
7.1.1 User commands 71
7.1.2 Buffered commands 73
7.2 MCTuningClass 74
7.3 How to create a user project that interacts with the MC API 75
7.4 Measurement units 77
7.4.1 Rotor angle 77
7.4.2 Rotor speed 78
7.4.3 Current measurement 78
7.4.4 Voltage measurement 78

8 LCD user interface 79
8.1 Running the motor control firmware using the LCD interface 79
8.2 LCD User interface structure 80
8.2.1 Motor control application layer configuration (speed sensor) 81
8.2.2 Welcome message 82
8.2.3 Configuration and debug page 82
8.2.4 Dual control panel page 87
8.2.5 Speed controller page 88
8.2.6 Current controllers page 90
8.2.7 Sensorless tuning STO & PLL page 93

8.2.8 Sensorless tuning STO & CORDIC page 95

9 User Interface class overview 98

9.1 User interface class (CUI) 99
9.2 User interface configuration 101
9.3 LCD manager class (CLCD_UI) 102
9.4 Using the LCD Manager 103
9.5 Motor control protocol class (CMCP_UI) 104
9.6 Using the motor control protocol 105
9.7 DAC Manager Class (CDACx_UI) 105
9.8 Using the DAC manager 107
9.9 How to configure the user defined DAC variables 108

10 Serial communication class overview 109

10.1 Set register frame 111
10.2 Get register frame 113
10.3 Execute command frame 114
10.4 Execute ramp frame 115
10.5 Get revup data frame 116
10.6 Set revup data frame 117
10.7 Set current references frame 118

11 Document conventions 120

Appendix A Additional information. 121

A.1 References 121

Revision history 121

List of figures

Figure 1. MC software library architecture . . . 10
Figure 2. Motor control library . . . 11
Figure 3. Example scenario . . . 12
Figure 4. Basic FOC algorithm structure, torque control . . . 16
Figure 5. Speed control loop . . . 16
Figure 6. Different PM motor constructions . . . 17
Figure 7. Assumed PMSM reference frame convention . . . 18
Figure 8. MTPA trajectory . . . 21
Figure 9. MTPA control . . . 21
Figure 10. Feed-forward current regulation . . . 23
Figure 11. Flux-weakening operation scheme . . . 24
Figure 12. PID general equation . . . 25
Figure 13. Time domain to discrete PID equations . . . 26
Figure 14. Block diagram of PI controller . . . 26
Figure 15. Closed loop block diagram . . . 27
Figure 16. Pole-zero cancellation . . . 27
Figure 17. Block diagram of closed loop system after pole-zero cancellation . . . 28
Figure 18. Vα and Vβ stator voltage components . . . 29
Figure 19. SVPWM phase voltage waveforms . . . 29
Figure 20. Transformation from an abc stationary frame to a rotating frame (q, d) . . . 31
Figure 21. Circle limitation working principle . . . 32
Figure 22. Three-shunt topology hardware architecture . . . 34
Figure 23. PWM and ADC synchronization . . . 35
Figure 24. Inverter leg and shunt resistor position . . . 36
Figure 25. Low-side switch gate signals (low modulation indexes) . . . 37
Figure 26. Low side Phase A duty cycle > DT+TN . . . 38
Figure 27. $(DT+T_N+T_S)/2 < \Delta Duty_A < D_T+T_N$ and $\Delta Duty_{AB} < D_T+T_R+T_S$ . . . 38
Figure 28. $\Delta DutyA < (DT+T_N+T_S)/2$ and $\Delta Duty_{A-B} > DT+T_R+T_S$ . . . 39
Figure 29. $\Delta Duty_A < (DT+T_N+T_S)/2$ and $\Delta Duty_{A-B} < DT+T_R+T_S$ . . . 39
Figure 30. Single-shunt hardware architecture . . . 40
Figure 31. Single-shunt current reading . . . 41
Figure 32. Boundary between two space-vector sectors . . . 42
Figure 33. Low modulation index . . . 43
Figure 34. Definition of noise parameters . . . 44
Figure 35. Regular region . . . 44
Figure 36. Boundary 1 . . . 45
Figure 37. Boundary 2 . . . 45
Figure 38. Boundary 3 . . . 46
Figure 39. ICS hardware architecture . . . 46
Figure 40. Stator currents sampling in ICS configuration . . . 47
Figure 41. General sensorless algorithm block diagram . . . 49
Figure 42. PMSM back-emfs detected by the sensorless state observer algorithm . . . 50
Figure 43. Hall sensors, output-state correspondence . . . 51
Figure 44. Hall sensor timer interface prescaler decrease . . . 52
Figure 45. Hall sensor timer interface prescaler increase . . . 52
Figure 46. TIMx_IRQHandler flowchart . . . 53
Figure 47. Hall sensor output transitions . . . 54
Figure 48. 60° and 120° displaced Hall sensor output waveforms . . . 55

Figure 49. Determination of Hall electrical phase shift . . . 56
Figure 50. Encoder output signals: counter operation . . . 57
Figure 51. MC workspace structure . . . 60
Figure 52. Workspace overview . . . 61
Figure 53. Workspace batch build . . . 62
Figure 54. MC Library project . . . 63
Figure 55. Motor control application project . . . 64
Figure 56. User project . . . 65
Figure 57. Flash loader wizard screen . . . 68
Figure 58. LCD UI project . . . 69
Figure 59. State machine flow diagram . . . 72
Figure 60. Radians vs s16 . . . 78
Figure 61. User interface reference . . . 79
Figure 62. Page structure and navigation . . . 80
Figure 63. STM32 Motor Control demonstration project welcome message . . . 82
Figure 64. Configuration and debug page . . . 83
Figure 65. Dual control panel page . . . 87
Figure 66. Speed controllers page . . . 89
Figure 67. Current controllers page . . . 91
Figure 68. Current controllers page with polar coordinates . . . 92
Figure 69. Iq, Id component versus Amp, Eps component . . . 93
Figure 70. Sensorless tuning STO & PLL page . . . 94
Figure 71. Example of rev-up sequence . . . 95
Figure 72. Sensorless tuning STO & CORDIC page . . . 96
Figure 73. Software layers . . . 98
Figure 74. User interface block diagram . . . 99
Figure 75. User interface configuration bit field . . . 101
Figure 76. LCD Manager block diagram . . . 103
Figure 77. Serial communication software layers . . . 104
Figure 78. Serial communication in motor control application . . . 109
Figure 79. Master-Slave communication architecture . . . 110
Figure 80. Set register frame . . . 111
Figure 81. Get register frame . . . 113
Figure 82. Execute command frame . . . 114
Figure 83. Execute ramp frame . . . 115
Figure 84. Speed ramp . . . 116
Figure 85. Get revup data frame . . . 116
Figure 86. Revup sequence . . . 117
Figure 87. Set revup data frame . . . 117
Figure 88. Set current reference frame . . . 118

List of tables

Table 1. References . . . 17
Table 2. Sector identification . . . 30
Table 3. 3-shunt current reading, used resources (single drive, F103 LD/MD) . . . 35
Table 4. 3-shunt current reading, used resources (single drive, or dual drive, F103 HD) . . . 36
Table 5. Current through the shunt resistor . . . 40
Table 6. Single shunt current reading, used resources (single drive, F103/F100 LD/MD) . . . 41
Table 7. Single shunt current reading, used resources (single or dual drive, F103HD) . . . 42
Table 8. ICS current reading, used resources (single drive, F103 LD/MD) . . . 47
Table 9. ICS current reading, used resources (single or dual drive, F103 HD) . . . 47
Table 10. Legend for *Figure 42* . . . 50
Table 11. File structure . . . 58
Table 12. Project configurations . . . 66
Table 13. Integrating the MC Interface in a user project . . . 75
Table 14. MC application preemption priorities . . . 76
Table 15. Priority configuration, overall (non FreeRTOS) . . . 76
Table 16. Priority configuration, overall (FreeRTOS) . . . 77
Table 17. Joystick actions and conventions . . . 79
Table 18. List of controls used in the LCD demonstration program . . . 81
Table 19. Definitions . . . 83
Table 20. List of DAC variables . . . 84
Table 21. DAC variables related to each state observer sensor when two state observer speed sensors are selected 85
Table 22. Fault conditions list . . . 86
Table 23. Control groups . . . 89
Table 24. Speed controllers page controls . . . 89
Table 25. Control groups . . . 91
Table 26. Current controllers page controls . . . 91
Table 27. Control groups . . . 93
Table 28. Sensorless tuning STO & PLL page controls . . . 94
Table 29. Control groups . . . 96
Table 30. Sensorless tuning STO & PLL page controls . . . 96
Table 31. User interface configuration - Sensor codes . . . 102
Table 32. User interface configuration - CFG bit descriptions . . . 102
Table 33. Description of relevant DAC variables . . . 106
Table 34. Generic starting frame . . . 110
Table 35. Starting frame codes . . . 110
Table 36. List of error codes . . . 111
Table 37. List of relevant motor control registers . . . 112
Table 38. List of commands . . . 114
Table 39. List of abbreviations . . . 120
Table 40. Document revision history . . . 121

Motor control library features

- Single or simultaneous Dual PMSM FOC sensorless / sensored (Dual PMSM FOC only when running on STM32F103xx High-Density, STM32F103xx XL-Density)
- Speed feedback:
  - Sensorless (B-EMF State Observer, PLL rotor speed/angle computation from B-EMF)
  - Sensorless (B-EMF State Observer, CORDIC rotor angle computation from B-EMF)
  - 60° or 120° displaced Hall sensors decoding, rising/falling edge responsiveness
  - Quadrature incremental encoder
  - For each motor, dual simultaneous speed feedback processing
  - On-the-fly speed sensor switching capability
- Current sampling methods:
  - Two ICS (only when running on STM32F103xx)
  - Single, common DC-link shunt resistor (ST patented)
  - Three shunt resistors placed on the bottom of the three inverter legs (only when running on STM32F103xx)
- Flux weakening algorithm to attain higher than rated motor speed (optional)
- Feed-Forward, high performance current regulation algorithm (optional)
- SVPWM generation:
  - Centered PWM pattern type
  - Adjustable PWM frequency
- Torque control mode, speed control mode; on-the-fly switching capability
- Brake strategies (optional):
  - Dissipative DC link brake resistor handling
  - Motor phases short-circuiting (with optional hardware over-current protection disabling)
- When running Dual FOC, any combination of the above-mentioned speed feedback, current sampling, control mode, optional algorithm
- Optimized I-PMSM and SM-PMSM drive
- Programmable speed ramps (parameters duration and final target)
- Programmable torque ramps (parameters duration and final target)
- Real-time fine tuning of:
  - PID regulators
  - Sensorless algorithm
  - Flux weakening algorithm
  - Start-up procedure (in case of sensorless)
- Fault conditions management:
  - Over-current
  - Over-voltage
  - Over-temperature
  - Speed feedback reliability error
  - FOC algorithm execution overrun

- Easy customization of options, pin-out assignments, CPU clock frequency through ST MC Workbench GUI
- C language code:
  - Compliant with MISRA-C 2004 rules
  - Conforms strictly with ISO/ANSI
  - Object-oriented programming architecture

User project and interface features

There are two available options:

- FreeRTOS-based user project (for STM32 performance line only)
- SysTick-timer-easy-scheduler-based user project

Available User Interface options (and combinations of them):

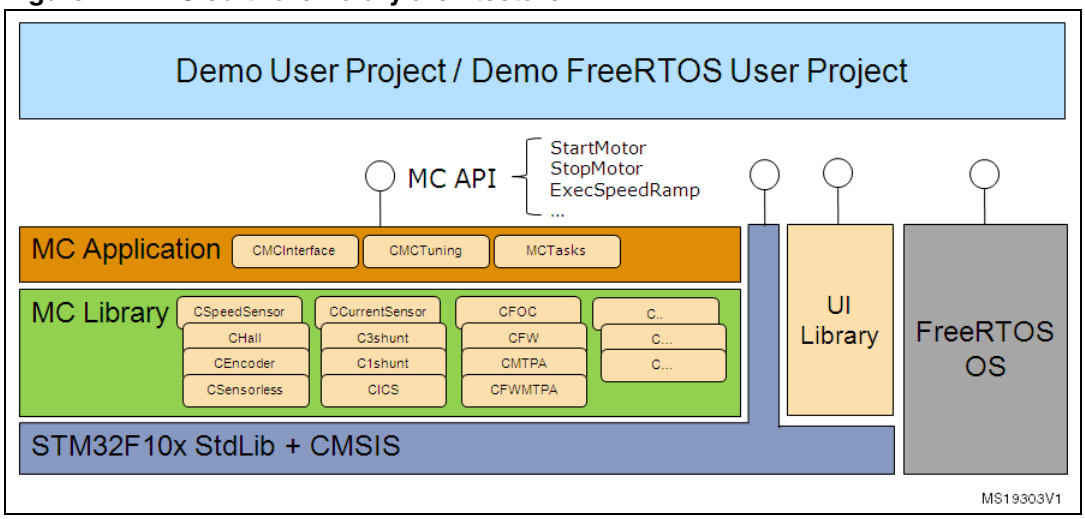
- LCD (C++ programmed) plus joystick
- Serial communication protocol
- Drive system variables logging/displaying via:
  - SPI
  - DAC (DAC peripheral available only on STM32F100xx or STM32F103xx High-Density and XL-Density; RC-filtered PWM signal option where not available)

1 MC software development kit architecture

Figure 1 shows the system architecture. The Motor Control SDK has a four-layer structure:

- STM32F10x standard peripherals library and CMSIS library
- Motor Control Library
- Motor Control Application
- Demonstration user project

Figure 1. MC software library architecture



From the bottom layer upwards:

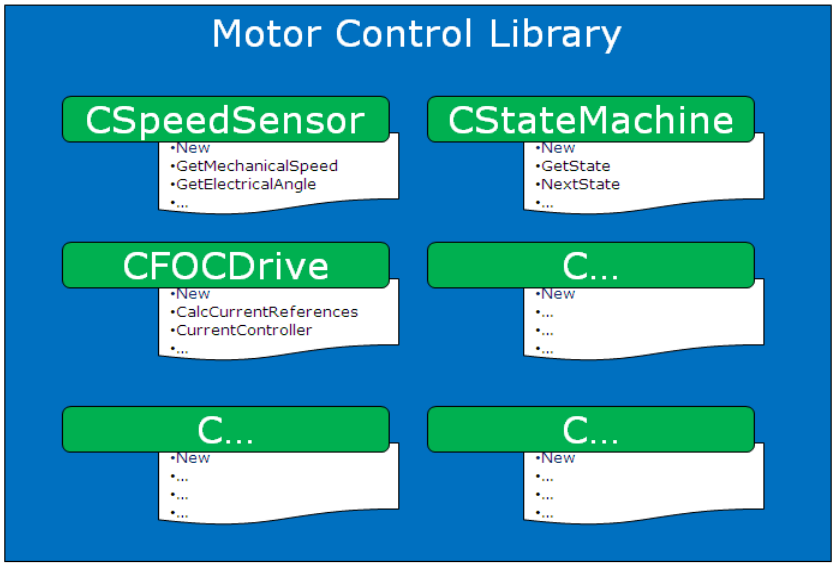
The STM32F10x Standard Peripherals Library is an independent firmware package that contains a collection of routines, data structures and macros that cover the features of the STM32 peripherals. Version 3.3.0 is included in the MC SDK. The STM32F10x Standard Peripherals Library is CMSIS and MISRA-C compliant. Visit www.st.com/stm32 for complete documentation.

The Motor Control Library is a wide collection of classes that describe the functionality of elements involved in motor control (such as speed sensors, current sensors, algorithms). Each class has an interface, which is a list of methods applicable to objects of that class. *Figure 2* is a conceptual representation of the library.

Two distributions of the Motor Control Library are available:

- Web distribution, available free of charge at www.st.com, where the Motor Control Library is provided as a compiled .lib file
- Confidential distribution, available free of charge on demand by contacting your nearest ST sales office or support team. Source classes files are provided, except for ST protected IPs, which are furnished as compiled object files. Source files of protected IPs can also be provided free of charge to ST partners upon request. Contact your nearest ST office or support team for further information.

Figure 2. Motor control library



The Motor Control Library uses the lower STM32F10x Standard Peripheral Library layer extensively for initializations and settings on peripherals. Direct access to STM32 peripheral registers is preferred when optimizations (in terms of execution speed or code size) are required. More information about the Motor Control Library, its classes and object oriented programming, can be found in the *Advanced developers guide for STM32F103xx/STM32F100xx PMSM single/dual FOC library* (UM1053).

The Motor Control Application (MCA) is an application that uses the Motor Control Library in order to accomplish commands received from the user level. This set of commands is specified in its Application Programming Interface (API).

During its boot stage, the MCA creates the required controls in accordance with actual system parameters, defined in specific .h files that are generated by the ST MC Workbench GUI (or manually edited). It coordinates them continuously for the purpose of accomplishing received commands, by means of tasks of proper priority and periodicity. More information about the MCA can be found in *Section 7: MC application programming interface (API)*, and details on tasks and implemented algorithms in the *Advanced developers guide for STM32F103xx/STM32F100xx PMSM single/dual FOC library* (UM1053).

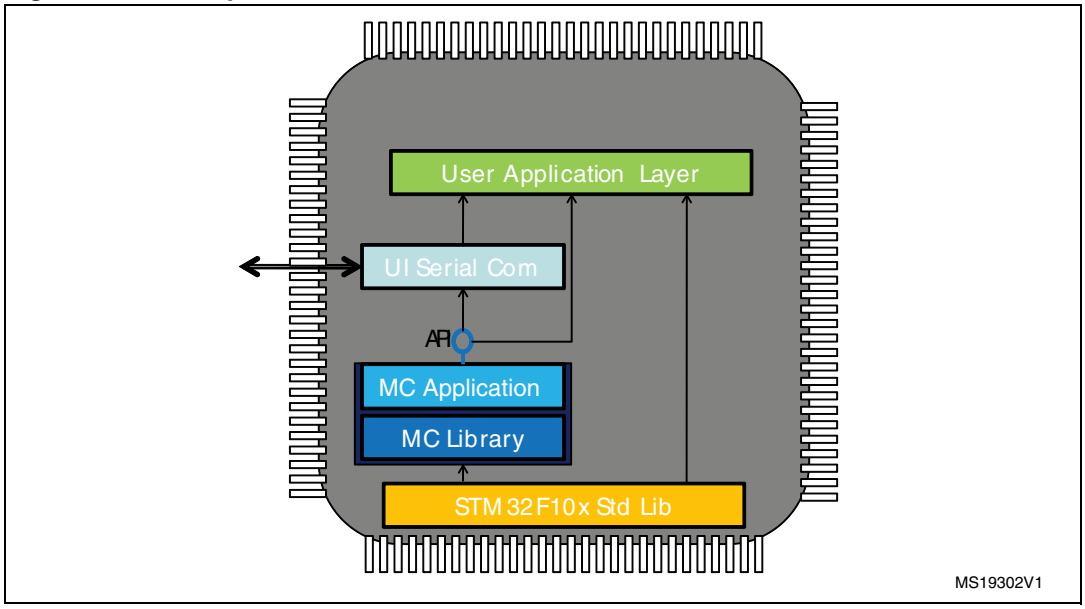
At the user level, a user project has been implemented to demonstrate how to interact with the MC API to successfully achieve the execution of commands. Depending on definable options, the user project can act as a Human Interface Device (using a joystick, buttons and LCD screens), as a command launcher through a serial communication protocol, as a data logging/displaying utility, or as a tuning tool.

Two versions of this user project are available. One is based on FreeRTOS, the other is not. The demonstration user project can be dismantled and replaced by the user application layer, or quite easily integrated, as shown in *Figure 3*: the user application layer uses the STM32F10x Standard Library for its own purposes, sends commands directly to the MC API, while the serial communication interface provided in the demonstration user project dispatches commands received from the outer world to the MC API.

More information about the modules integrated with the demonstration user project, such as serial communication protocol, drive variables monitoring through DAC / SPI, HID

(generically called 'UI library') and a description of LCD screens can be found in *Section 8: LCD user interface* and *Section 9: User Interface class overview*.

Figure 3. Example scenario



2 Documentation architecture

2.1 Where to find the information you need

Technical information about the MC SDK is distinguished and organized by topic. The following is a list of the documents that are available and the subjects they cover:

- This manual (UM1052), STM32F103xx/STM32F100xx permanent-magnet synchronous motor single/dual FOC software library V3.0. This provides the following:
  - Features
  - Architecture
  - Workspace
  - Customization processes
  - Overview of algorithms implemented (FOC, current sensors, speed sensors)
  - MC API
  - Demonstrative user project
  - Demonstrative LCD user interface
  - Demonstrative serial communication protocol
- *Advanced developers guide for STM32F103xx/STM32F100xx PMSM single/dual FOC library* (UM1053). This provides the following:
  - Object-oriented programming style used for developing the MC library
  - Description of classes that belong to the MC library
  - Interactions between classes
  - Description of tasks of the MCA
- MC library source documentation (Doxygen-compiled HTML file). This provides a full description of the public interface of each class of the MC library (methods, parameters required for object creation).
- MC Application source documentation (Doxygen-compiled HTML file). This provides a full description of the classes that make up the MC API.
- User Interface source documentation (Doxygen-compiled HTML file). This provides a full description of the classes that make up the UI Library.
- STM32F10x Standard Peripherals Library source documentation (doxygen compiled html file).
- ST MC Workbench GUI documentation. This is a field guide that describes the steps and parameters required to customize the library, as shown in the GUI.
- In-depth documentation about particular algorithms (sensorless position/speed detection, flux weakening, MTPA, feed-forward current regulation).

Please contact your nearest ST sales office or support team to obtain the documentation you are interested in if it was not already included in the software package you received or available on the ST web site (*www.st.com*).

2.2 Related documents

Available from www.arm.com

- Cortex™-M3 Technical Reference Manual, available from: *http://infocenter.arm.com/help/topic/com.arm.doc.ddi0337e/DDI0337E_cortex_m3_r1p1_trm.pdf*

Available from www.st.com or your STMicroelectronics sales office

- *STM32F103xx datasheet*
- *STM32F100xx datasheet*
- *STM32F103xx user manual (RM0008)*
- *STM32F100xx user manual (RM0041)*
- *STM32F103xx AC induction motor IFOC software library V2.0 (UM0483)*
- *STM32 and STM8 Flash Loader demonstrator (UM0462)*

3 Overview of the FOC and other implemented algorithms

3.1 Introduction to the PMSM FOC drive

This software library is designed to achieve the high dynamic performance in AC permanent-magnet synchronous motor (PMSM) control offered by the well-established field oriented control (FOC) strategy.

With this approach, it can be stated that, by controlling the two currents i_{qs} and i_{ds}, which are mathematical transformations of the stator currents, it is possible to offer electromagnetic torque (T_e) regulation and, to some extent, flux weakening capability.

This resembles the favorable condition of a DC motor, where those roles are held by the armature and field currents.

Therefore, it is possible to say that FOC consists of controlling and orienting stator currents in phase and quadrature with the rotor flux; this definition makes clear that a means of measuring stator currents and the rotor angle is needed.

Basic information on the algorithm structure (and then on the library functions) is represented in *Figure 4*.

- The i_{qs} and i_{ds} current references can be selected to perform electromagnetic torque and flux control.
- The space vector PWM block (SVPWM) implements an advanced modulation method that reduces current harmonics, thus optimizing DC bus exploitation.
- The current reading block allows the system to measure stator currents correctly, using either cheap shunt resistors or market-available isolated current Hall sensors (ICS).
- The rotor speed/position feedback block allows the system to handle Hall sensor or incremental encoder signals in order to correctly acquire the rotor angular velocity or position. Moreover, this firmware library provides sensorless detection of rotor speed/position.
- The PID-controller blocks implement proportional, integral and derivative feedback controllers (current regulation).
- The Clarke, Park, Reverse Park & Circle limitation blocks implement the mathematical transformations required by FOC.

Figure 4. Basic FOC algorithm structure, torque control

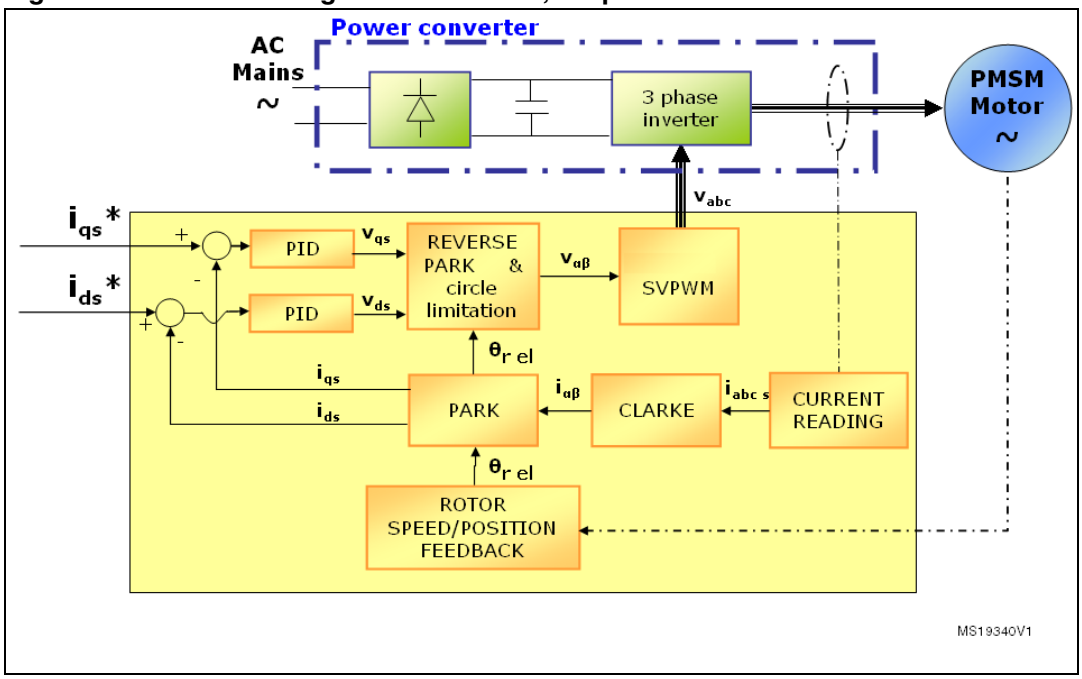


Figure 5. Speed control loop

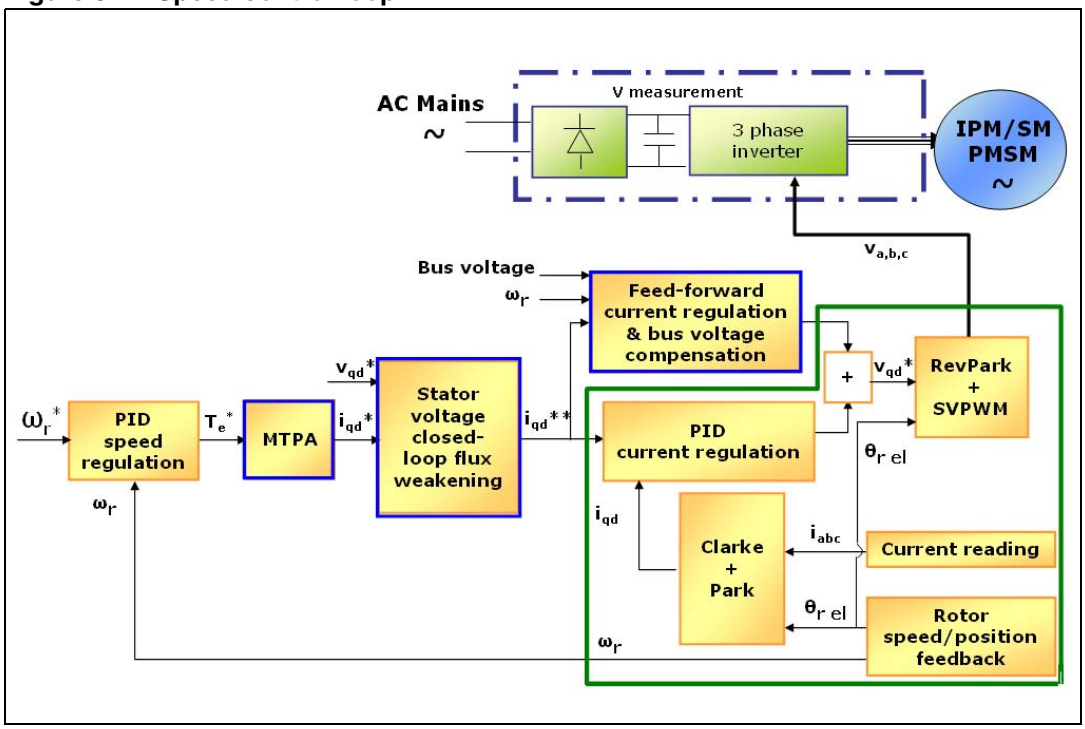


Table 1. References

Reference	Detail
Section 3.4: PMSM maximum torque per ampere (MTPA) control	Explains the MTPA (maximum-torque-per-ampere) strategy optimized for IPMSM.
Section 3.6: Flux-weakening control	Explains flux-weakening control.
Section 3.5: Feed-forward current regulation	Shows how to take advantage of the feed-forward current regulation.

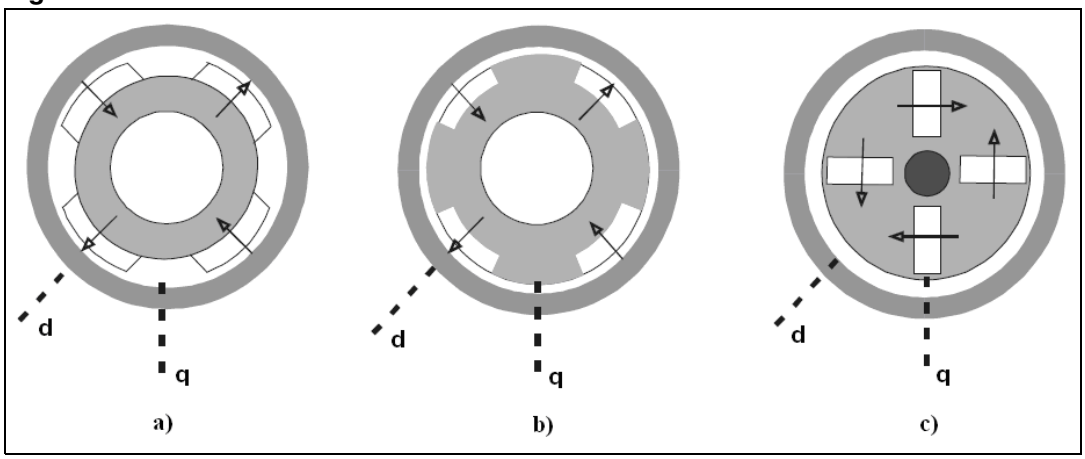
Figure 5: Speed control loop shows the speed control loop built around the 'core' torque control loop, plus additional specific features offered by this Motor Control Library (see *Table 1: References*). Each of them can be set as an option, depending on the motor being used and user needs, via the ST MC Workbench GUI, which generates the .h file used to correctly initialize the MCA during its boot stage.

3.2 PM motor structures

Two different PM motor constructions are available:

- In drawing a) in *Figure 6*, the magnets are glued to the surface of the rotor, and this is the reason why it is referred to as SM-PMSM (surface mounted PMSM)
- In drawings b) and c) in *Figure 6*, the magnets are embedded in the rotor structure. This construction is known as IPMSM (interior PMSM)

Figure 6. Different PM motor constructions



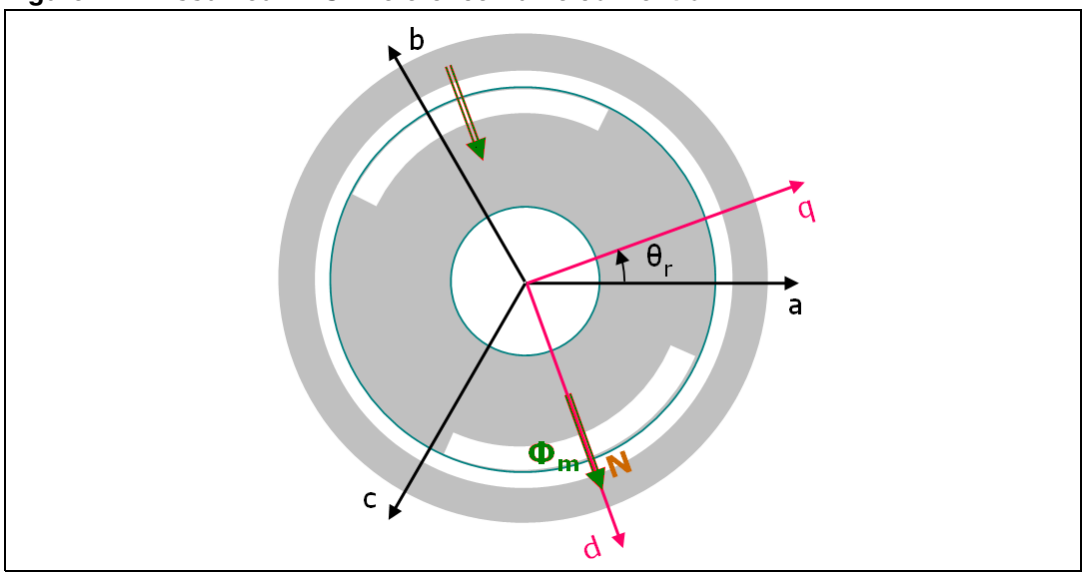
SM-PMSMs inherently have an isotropic structure, which means that the direct and quadrature inductances L_d and L_q are the same. Usually, their mechanical structure allows a wider airgap, which, in turn, means lower flux weakening capability.

On the other hand, IPMSMs show an anisotropic structure (with $L_d < L_q$, typically), slight in the b) construction (called inset PM motor), strong in the c) configuration (called buried or radial PM motor). This peculiar magnetic structure can be exploited (as explained in *Section 3.4*) to produce a greater amount of electromagnetic torque. their fine mechanical structure usually shows a narrow airgap, thus giving good flux weakening capability.

This firmware library is optimized for use in conjunction with SM-PMSMs and IPMSMs. machines.

3.3 PMSM fundamental equations

Figure 7. Assumed PMSM reference frame convention



With reference to *Figure 7*, the motor voltage and flux linkage equations of a PMSM (SM-PMSM or IPMSM) are generally expressed as:

$$v_{abc_s} = r_s i_{abc_s} + \frac{d\lambda_{abc_s}}{dt}$$

$$\lambda_{abc_s} = \begin{bmatrix} L_{ls}+L_{ms} & -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & L_{ls}+L_{ms} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} & L_{ls}+L_{ms} \end{bmatrix} i_{abc_s} + \begin{bmatrix} \sin\theta_r \\ \sin\left(\theta_r - \frac{2\pi}{3}\right) \\ \sin\left(\theta_r + \frac{2\pi}{3}\right) \end{bmatrix} \Phi_m$$

where:

- r_s is the stator phase winding resistance
- L_{ls} is the stator phase winding leakage inductance
- L_{ms} is the stator phase winding magnetizing inductance; in case of an IPMSM, self and mutual inductances have a second harmonic component L_{2s} proportional to $\cos(2\theta_r + k \times 2\pi/3)$, with $k = 0 \pm 1$, in addition to the constant component L_{ms}(neglecting higher-order harmonics)
- θ_r is the rotor electrical angle
- Φ_m is the flux linkage due to permanent magnets

The complexity of these equations is apparent, as the three stator flux linkages are mutually coupled and, what is more, as they are dependent on the rotor position, which is time-varying and a function of the electromagnetic and load torques.

The reference frame theory simplifies the PM motor equations by making a change of variables that refers the stator quantities abc (that can be visualized as directed along axes each 120° apart) to q_d components, directed along a 90° apart axes, rotating synchronously with the rotor, and vice versa. The d “direct” axis is aligned with the rotor flux, while the q “quadrature” axis leads at 90 degrees in the positive rolling direction.

The motor voltage and flux equations are simplified to:

$$\begin{cases} v_{qs} = r_s i_{qs} + \frac{d\lambda_{qs}}{dt} + \omega_t \lambda_{ds} \\ v_{ds} = r_s i_{ds} + \frac{d\lambda_{ds}}{dt} - \omega_t \lambda_{qs} \end{cases}$$

$$\begin{cases} \lambda_{qs} = L_{qs} i_{qs} \\ \lambda_{ds} = L_{ds} i_{ds} + \Phi_m \end{cases}$$

For an SM-PMSM, the inductances of the d- and q- axis circuits are the same (refer to *Section 3.2*), that is we have:

$$L_s = L_{qs} = L_{ds} = L_{ls} + \frac{3L_{ms}}{2}$$

On the other hand, IPMSMs show a salient magnetic structure, so their inductances can be written as:

$$L_{qs} = L_{ls} + \frac{3(L_{ms} + L_{2s})}{2}$$

$$L_{ds} = L_{ls} + \frac{3(L_{ms} - L_{2s})}{2}$$

3.3.1 SM-PMSM field-oriented control (FOC)

The equations below describe the electromagnetic torque of an SM-PMSM:

$$T_e = \frac{3}{2}\bar{p}(\lambda_{d_s} i_{q_s} - \lambda_{q_s} i_{d_s}) = \frac{3}{2}\bar{p}(L_s i_{d_s} i_{q_s} + \Phi_m i_{q_s} - L_s i_{q_s} i_{d_s})$$

$$T_e = \frac{3}{2}\bar{p}(\Phi_m i_{q_s})$$

The last equation makes it clear that the quadrature current component i_{qs} has linear control on the torque generation, whereas the current component i_{ds} has no effect on it (as mentioned above, these equations are valid for SM-PMSMs).

Therefore, if I_s is the motor rated current, then its maximum torque is produced for $i_{qs} = I_s$ and $i_{ds} = 0$ (in fact $I_s = \sqrt{i_{q_s}^2 + i_{d_s}^2}$). In any case it is clear that, when using an SM-PMSM, the torque/current ratio is optimized by letting $i_{ds} = 0$. This choice therefore corresponds to the MTPA (maximum-torque-per-ampere) control for isotropic motors.

On the other hand, the magnetic flux can be weakened by acting on the direct axis current i_{ds}; this extends the achievable speed range, but at the cost of a decrease in maximum quadrature current i_{qs}, and hence in the electromagnetic torque supplied to the load (see *Section 3.6: Flux-weakening control* for details about the Flux weakening strategy).

In conclusion, by regulating the motor currents through their components i_{qs} and i_{ds}, FOC manages to regulate the PMSM torque and flux; current regulation is achieved by means of what is usually called a “synchronous frame CR-PWM”.

3.4 PMSM maximum torque per ampere (MTPA) control

The electromagnetic torque equation of an IPMSM is:

$$T_e = \frac{3}{2}\bar{p}(\lambda_{ds}i_{qs} - \lambda_{qs}i_{ds}) = \frac{3}{2}\bar{p}(L_{ds}i_{ds}i_{qs} + \Phi_m i_{qs} - L_{qs}i_{qs}i_{ds})$$

$$T_e = \frac{3}{2}\bar{p}\Phi_m i_{qs} + \frac{3}{2}\bar{p}L_{ds} - L_{qs}i_{qs}i_{ds}$$

The first term in this expression is the PM excitation torque. The second term is the so-called reluctance torque, which represents an additional component due to the intrinsic salient magnetic structure. Besides, since $L_d < L_q$ typically, reluctance and excitation torques have the same direction only if $i_{ds} < 0$.

Considering the torque equation, it can be pointed out that the current components i_{qs} and i_{ds} both have a direct influence on torque generation.

The aim of the MTPA (maximum-torque-per-ampere) control is to calculate the reference currents (i_{qs}, i_{ds}) which maximize the ratio between produced electromagnetic torque and copper losses (under the following condition).

$$I_s = \sqrt{i_{qs}^2 + i_{ds}^2} \leq I_n$$

Therefore, given a set of motor parameters (pole pairs, direct and quadrature inductances L_d and L_q, magnets flux linkage, nominal current) the MTPA trajectory is identified as the locus of (i_{qs}, i_{ds}) pairs that minimizes the current consumption for each required torque (see *Figure 8*).

This feature can be activated through correct settings in .h parameter files (generated by the ST MC Workbench GUI) used to initialize the MC Application during its boot stage.

In confidential distribution, the classes that implement the MTPA algorithm are provided as compiled object files. The source code is available free of charge from ST on request. Please contact your nearest ST sales office.

Figure 8. MTPA trajectory

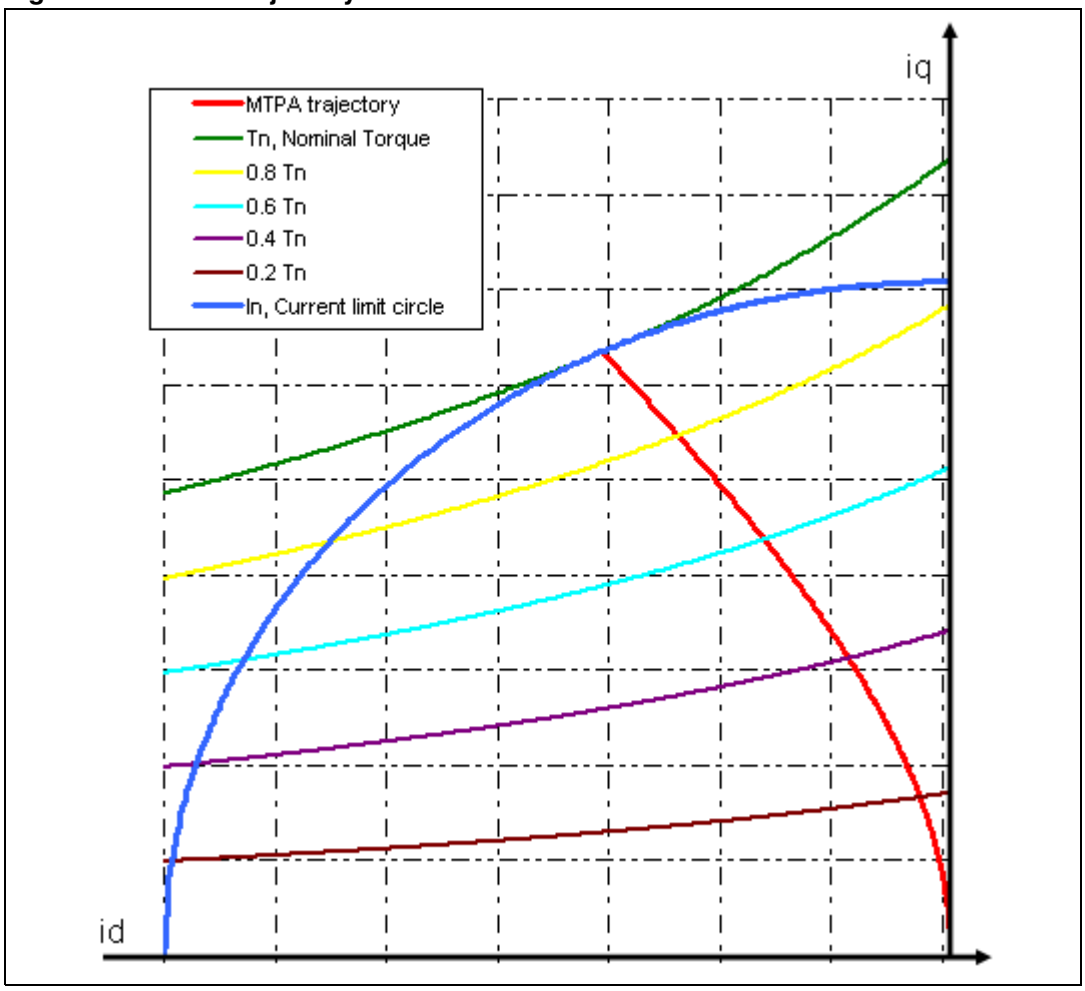
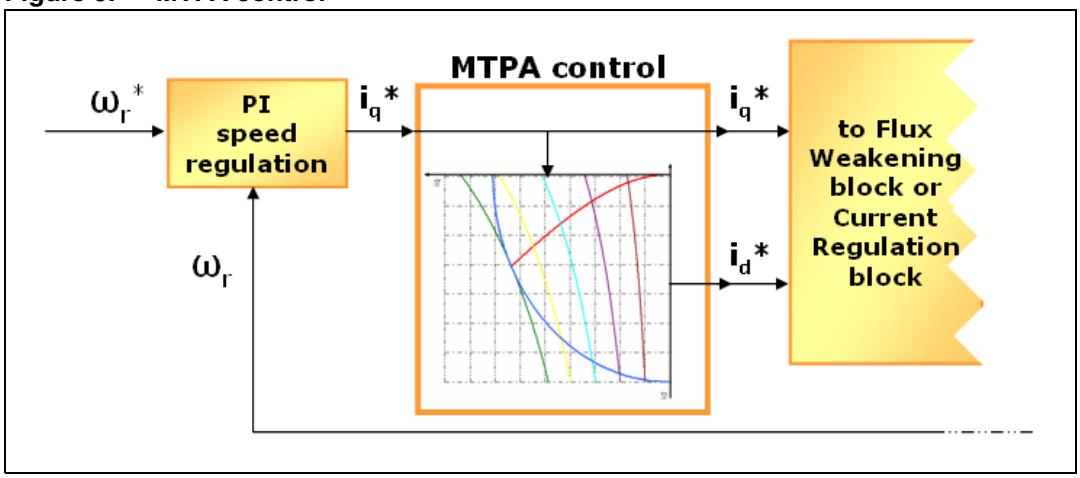


Figure 9 shows the MTPA strategy implemented inside a speed-control loop. In this case, i_{q*} (output of the PI regulator) is fed to the MTPA function, i_{d*} is chosen by entering the linear interpolated trajectory.

Figure 9. MTPA control



In all cases, by acting on the direct axis current i_{ds}, the magnetic flux can be weakened so as to extend the achievable speed range. As a consequence of entering this operating region, the MTPA path is left (see *Section 3.6: Flux-weakening control* for details about the flux-weakening strategy).

In conclusion, by regulating the motor currents through their i_{qs} and i_{ds} components, FOC manages to regulate the PMSM torque and flux. Current regulation is then achieved by means of what is usually called a “synchronous frame CR-PWM”.

3.5 Feed-forward current regulation

The feed-forward feature provided by this firmware library aims at improving the performance of the CR-PWM (current-regulated pulse width modulation) part of the motor drive.

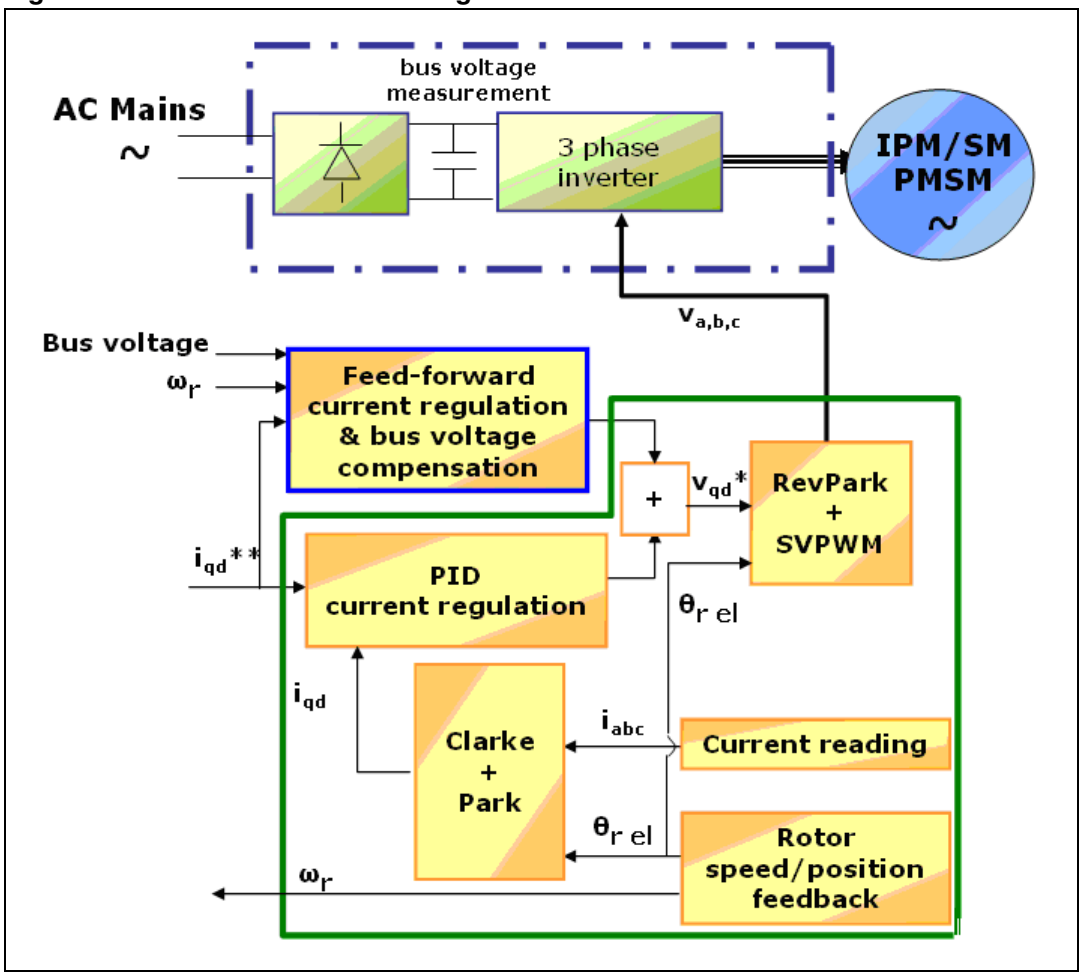
It calculates in advance the v_q* and v_d* stator voltage commands required to feed the motor with the i_q** and i_d** current references. By doing so, it backs up the standard PID current regulation (see *Figure 10*).

The feed-forward feature works in the synchronous reference frame and requires good knowledge of some machine parameters, such as the winding inductances L_d and L_q (or L_s if an SM-PMSM is used) and the motor voltage constant K_e.

The feed-forward algorithm has been designed to compensate for the frequency-dependent back emf’s and cross-coupled inductive voltage drops in permanent magnet motors. As a result, the q-axis and d-axis PID current control loops become linear, and a high performance current control is achieved.

As a further effect, since the calculated stator voltage commands v_q* and v_d* are compensated according to the present DC voltage measurement, a bus voltage ripple compensation is accomplished.

Figure 10. Feed-forward current regulation



Depending on certain overall system parameters, such as the DC bulk capacitor size, electrical frequency required by the application, and motor parameters, the feed-forward functionality can provide a major or a poor contribution to the motor drive. It is therefore recommended that you assess the resulting system performance and enable the functionality only if a valuable effect is measured.

This feature can be activated through proper settings in .h parameter files (generated by the ST MC Workbench GUI) used to initialize the MCA during its boot stage.

In confidential distribution, the classes that implement the feed-forward algorithm are provided as compiled object files. The source code is available free of charge from ST on request. Please contact your nearest ST sales office.

3.6 Flux-weakening control

The purpose of the flux-weakening functionality is to expand the operating limits of a permanent-magnet motor by reaching speeds higher than rated, as many applications require under operating conditions where the load is lower than rated. Here, the rated speed is considered to be the highest speed at which the motor can still deliver maximum torque.

The magnetic flux can be weakened by acting on direct axis current i_d; given a motor rated current I_n, such that $I_n = \sqrt{i_q^2 + i_d^2}$, if we choose to set id ≠ 0, then the maximum available quadrature current i_q is reduced. Consequently, in case of an SM-PMSM, as shown in *Section 3.3.1*, the maximum deliverable electromagnetic torque is also reduced. On the other hand, for an IPM motor, acting separately on i_d causes a deviation from the MTPA path (as explained in *Section 3.4: PMSM maximum torque per ampere (MTPA) control*).

"Closed-loop" flux weakening has been implemented. Accurate knowledge of machine parameters is not required, which strongly reduces sensitivity to parameter deviation (see [3]-[4] in Appendix *Section A.1: References*). This scheme is suitable for both IPMSMs and SM-PMSMs.

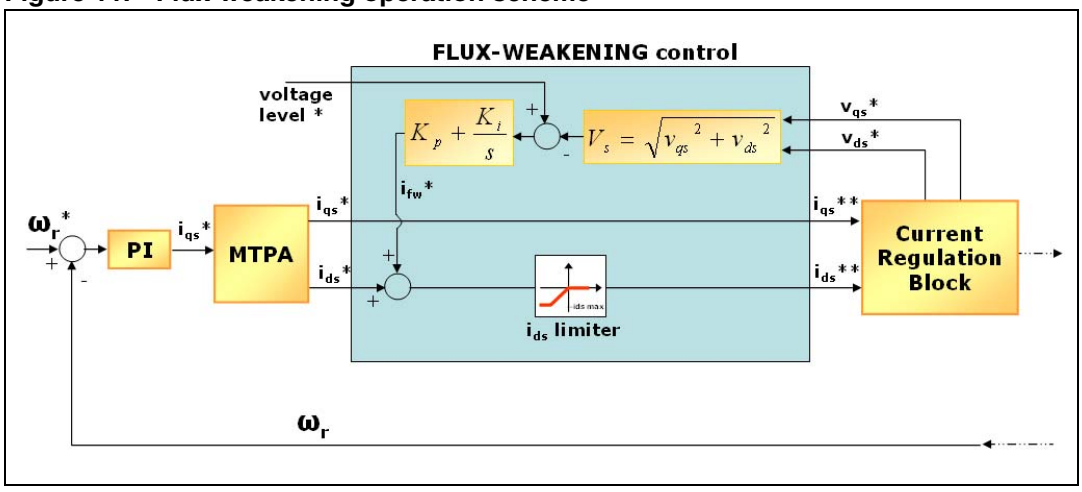
The control loop is based on stator voltage monitoring (*Figure 11* shows the diagram).

The current regulator output V_s is checked against a settled threshold ("voltage level*" parameter). If V_s is beyond that limit, the flux-weakening region is entered automatically by regulating a control signal, i_{fw}*, that is summed up to i_{ds}*, the output of the MTPA controller. This is done by means of a PI regulator (whose gain can be tuned in real-time) in order to prevent the saturation of the current regulators. It clearly appears, then, that the higher the voltage level* parameter is settled (by keeping up current regulation), the higher the achieved efficiency and maximum speed.

If V_s is smaller than the settled threshold, then i_{fw} decreases to zero and the MTPA block resumes control.

The current i_{ds}** output from the flux-weakening controller must be checked against i_{ds} max to avoid the demagnetization of the motor.

Figure 11. Flux-weakening operation scheme



This feature can be activated through correct settings in .h parameter files (generated by the ST MC Workbench GUI) used to initialize the MC Application during its 'boot' stage.

In confidential distribution, the classes that implement the flux weakening algorithm are provided as compiled object files. The source code is available free of charge from ST on request. Please contact your nearest ST sales office.

3.7 PID regulator theoretical background

The regulators implemented for Torque, Flux and Speed are actually Proportional Integral Derivative (PID) regulators. PID regulator theory and tuning methods are subjects which have been extensively discussed in technical literature. This section provides a basic reminder of the theory.

PID regulators are useful to maintain a level of torque, flux or speed according to a desired target.

Figure 12. PID general equation

torque = f(rotor position)
flux = f(rotor position)
} torque and flux regulation for maximum system efficiency

torque = f(rotor speed)
} torque regulation for speed regulation of the system

Where: $Error_{sys_T}$ Error of the system observed at time t = T

$Error_{sys_{T-1}}$ Error of the system observed at time t = T - Tsampling

$$f(X_T) = K_p \times Error_{sys_T} + K_i \times \sum_{0}^{T} Error_{sys_t} + K_d \times (Error_{sys_T} - Error_{sys_{T-1}}) \quad (1)$$

Derivative term can be disabled

Equation 1 corresponds to a classical PID implementation, where:

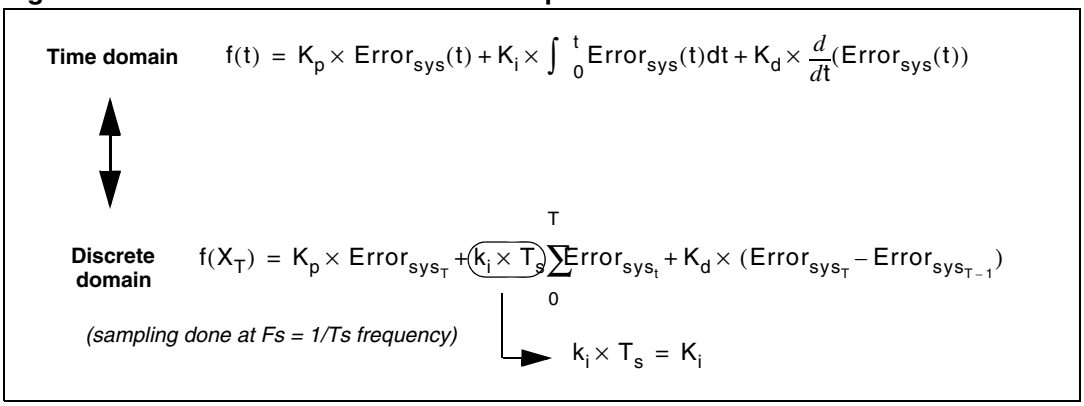
- K_p is the proportional coefficient,
- K_i is the integral coefficient.
- K_d is the differential coefficient.

3.7.1 Regulator sampling time setting

The sampling time needs to be modified to adjust the regulation bandwidth. As an accumulative term (the integral term) is used in the algorithm, increasing the loop time decreases its effects (accumulation is slower and the integral action on the output is delayed). Inversely, decreasing the loop time increases its effects (accumulation is faster and the integral action on the output is increased). This is why this parameter has to be adjusted prior to setting up any coefficient of the PID regulator.

In order to keep the CPU load as low as possible and as shown in equation (1) in *Figure 12*, the sampling time is directly part of the integral coefficient, thus avoiding an extra multiplication. *Figure 13* describes the link between the time domain and the discrete system.

Figure 13. Time domain to discrete PID equations


Time domain
$f(t) = K_p \times Error_{sys}(t) + K_i \times \int_0^t Error_{sys}(t)dt + K_d \times \frac{d}{dt}(Error_{sys}(t))$
Discrete domain
$f(X_T) = K_p \times Error_{sys_T} + (k_i \times T_s) \sum_0^T Error_{sys_t} + K_d \times (Error_{sys_T} - Error_{sys_{T-1}})$
(sampling done at Fs = 1/Ts frequency)
$k_i \times T_s = K_i$

In theory, the higher the sampling rate, the better the regulation. In practice, you must keep in mind that:

- The related CPU load will grow accordingly.
- For speed regulation, there is absolutely no need to have a sampling time lower than the refresh rate of the speed information fed back by the external sensors; this becomes especially true when Hall sensors are used while driving the motor at low speed.

3.8 A priori determination of flux and torque current PI gains

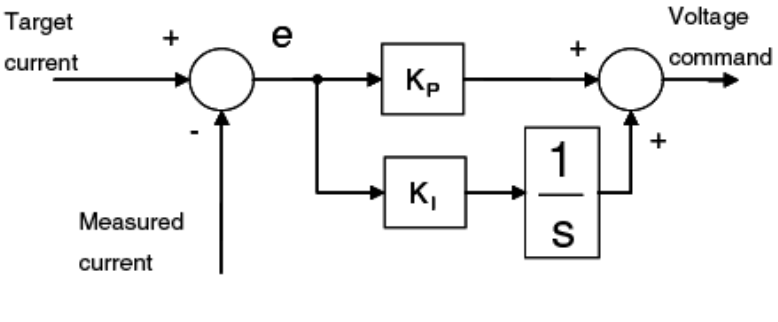
This section provides a criterion for the computation of the initial values of the torque/flux PI parameters (K_I and K_P). This criterion is also used by the ST MC Workbench in its computation.

To calculate these starting values, it is required to know the electrical characteristics of the motor: stator resistance R_s and inductance L_s and the electrical characteristics of the hardware: shunt resistor R_{Shunt}, current sense amplification network A_{Op} and the direct current bus voltage $V_{Bus}DC$.

The derivative action of the controller is not considered using this method.

Figure 14 shows the PI controller block diagram used for torque or flux regulation.

Figure 14. Block diagram of PI controller

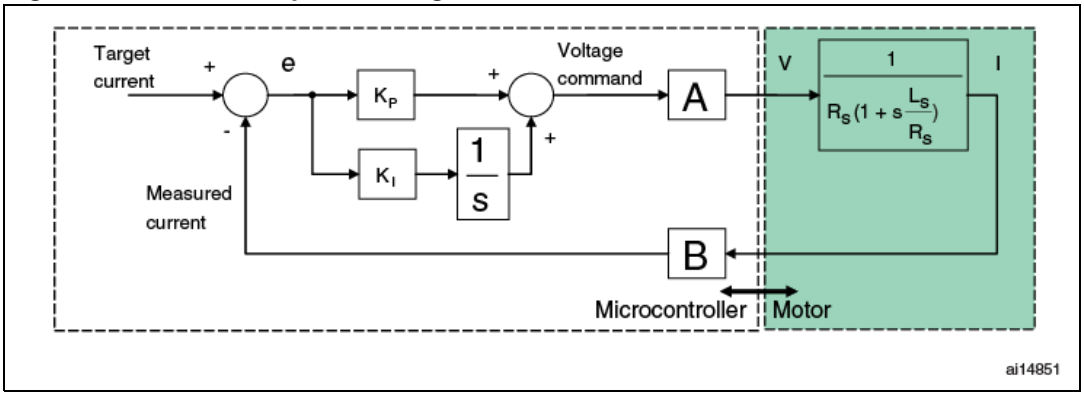


For this analysis, the motor electrical characteristics are assumed to be isotropic with respect to the q and d axes. It is assumed that the torque and flux regulators have the same starting value of K_P and that they also have the same K_I value.

Figure 15 shows the closed loop system in which the motor phase is modelled using the resistor-inductance equivalent circuit in the “locked-rotor” condition.

Block “A” is the proportionality constant between the software variable storing the voltage command (expressed in digit) and the real voltage applied to the motor phase (expressed in Volt). Likewise, block “B” is the is the proportionality constant between the real current (expressed in Ampere) and the software variable storing the phase current (expressed in digit).

Figure 15. Closed loop block diagram

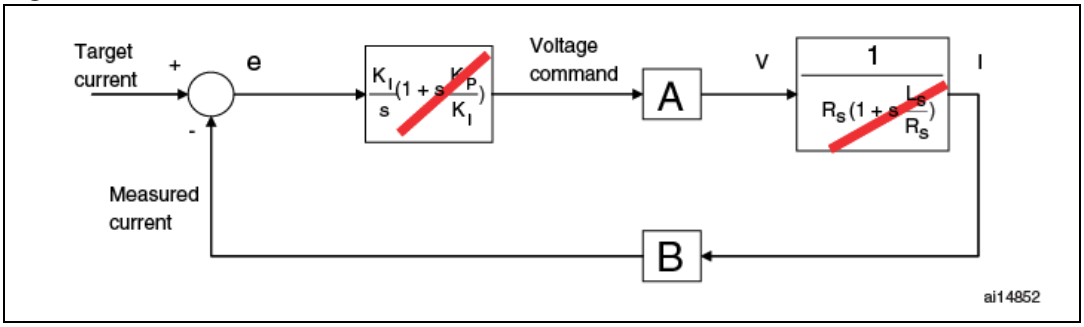


The transfer functions of the two blocks “A” and “B” are expressed by the following formulas:

$A = \frac{V_{Bus}DC}{2^{16}}$ and $B = \frac{R_{shunt}A_{op}2^{16}}{3.3}$, respectively.

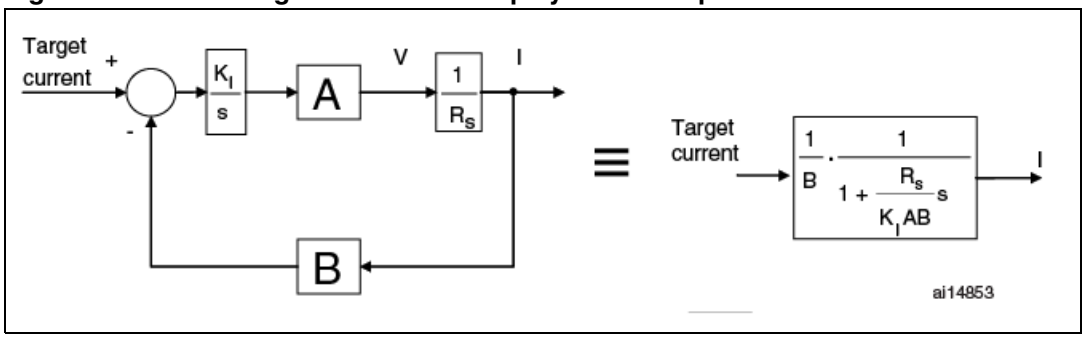
By putting $K_P/K_I = L_S/R_S$, it is possible to perform pole-zero cancellation as described in *Figure 16*.

Figure 16. Pole-zero cancellation



In this condition, the closed loop system is brought back to a first-order system and the dynamics of the system can be assigned using a proper value of K_I. See *Figure 17*.

Figure 17. Block diagram of closed loop system after pole-zero cancellation



It is important to note that the parameters used inside the PI algorithms must be integer numbers, so calculated KI and KP values have to be expressed as fractions (dividend/divisor).

Moreover the PI algorithm does not include the PI sampling time (T) in the computation of the integral part. See the following formula:

$$k_i \int_0^t e(\tau)d\tau = k_i T \sum_{k=1}^{n} e(kT) = K_i \sum_{k=1}^{n} e(kT)$$

Since the integral part of the controller is computed as a sum of successive errors, it is required to include T in the K_I computation.

So the final formula can be expressed as:

$$K_P = L_S \frac{\omega_C}{AB} K_P DIV$$

$$K_i = \frac{R_S \cdot \omega_C \cdot K_i DIV}{AB} \cdot T$$

$$AB = \frac{V_{Bus}DC \cdot R_{shunt} \cdot A_{op}}{3.3}$$

Usually, it is possible to set ω_C (the bandwidth of the closed loop system) to 1500 rad/s, to obtain a good trade-off between dynamic response and sensitivity to the measurement noise.

3.9 Space vector PWM implementation

Figure 18 shows the stator voltage components V_α and V_β while *Figure 19* illustrates the corresponding PWM for each of the six space vector sectors.

Figure 18. V_α and V_β stator voltage components

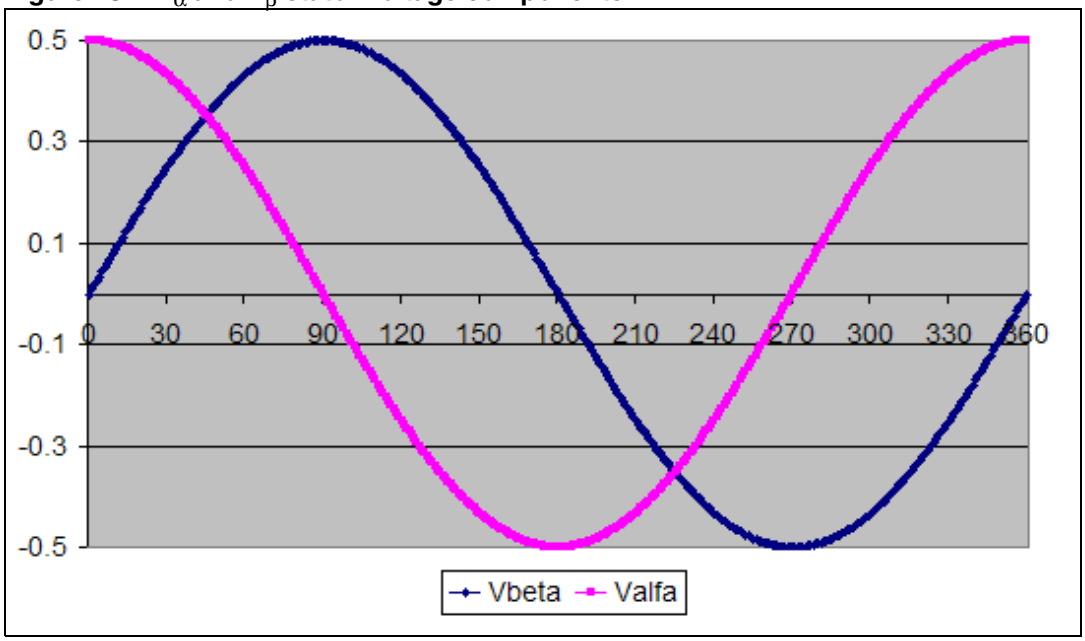
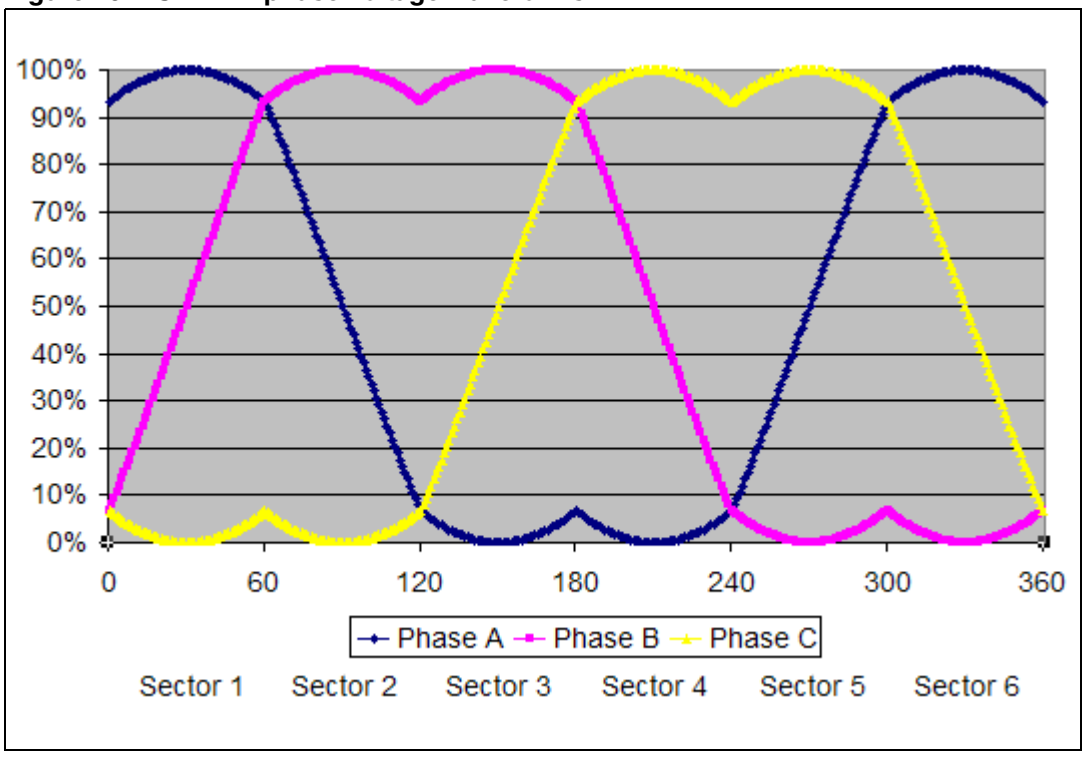


Figure 19. SVPWM phase voltage waveforms



With the following definitions for: $U_\alpha = \sqrt{3} \times T \times V_\alpha$, $U_\beta = -T \times V_\beta$ and $X = U_\beta$, $Y = \frac{U_\alpha + U_\beta}{2}$ and $Z = \frac{U_\beta - U_\alpha}{2}$.
literature demonstrates that the space vector sector is identified by the conditions shown in *Table 2*.

Table 2. Sector identification

	Y < 0			Y ≥ 0		
	Z < 0	Z ≥ 0		Z < 0		Z ≥ 0
		X ≤ 0	X > 0	X ≤ 0	X > 0	
Sector	V	IV	III	VI	I	II

The duration of the positive pulse widths for the PWM applied on Phase A, B and C are respectively computed by the following relationships:

Sector I, IV: $t_A = \frac{T + X - Z}{2}$, $t_B = t_A + Z$, $t_C = t_B - X$

Sector II, V: $t_A = \frac{T + Y - Z}{2}$, $t_B = t_A + Z$, $t_C = t_A - Y$

Sector III, VI: $t_A = \frac{T - X + Y}{2}$, $t_B = t_C + X$, $t_C = t_A - Y$, where T is the PWM period.

Now, considering that the PWM pattern is center aligned and that the phase voltages must be centered at 50% of duty cycle, it follows that the values to be loaded into the PWM output compare registers are given respectively by:

Sector I, IV: $\text{TimePhA} = \frac{T}{4} + \frac{T/2 + X - Z}{2}$, $\text{TimePhB} = \text{TimePhA} + Z$, $\text{TimePhC} = \text{TimePhB} - X$

Sector II, V: $\text{TimePhA} = \frac{T}{4} + \frac{T/2 + Y - Z}{2}$, $\text{TimePhB} = \text{TimePhA} + Z$, $\text{TimePhC} = \text{TimePhA} - Y$

Sector III,VI: $\text{TimePhA} = \frac{T}{4} + \frac{T/2 + Y - X}{2}$, $\text{TimePhB} = \text{TimePhC} + X$, $\text{TimePhC} = \text{TimePhA} - Y$

3.10 Detailed explanation about reference frame transformations

PM synchronous motors show very complex and time-varying voltage equations.

By making a change of variables that refers stator quantities to a frame of reference synchronous with the rotor, it is possible to reduce the complexity of these equations.

This strategy is often referred to as the Reference-Frame theory [1].

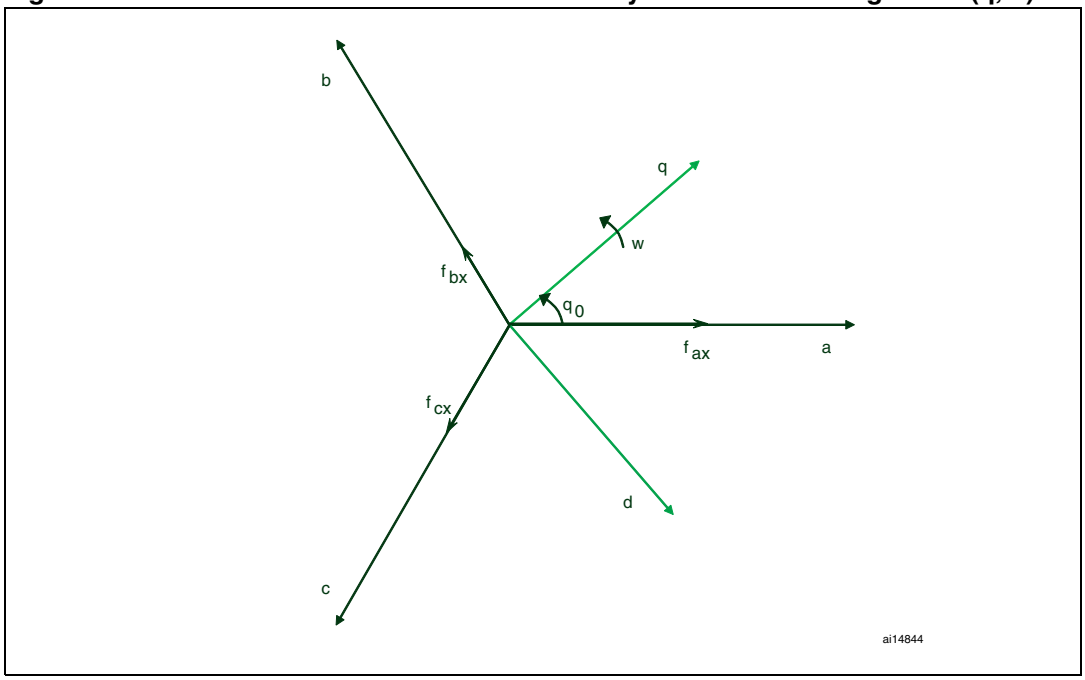
Supposing f_{ax}, f_{bx}, f_{cx} are three-phase instantaneous quantities directed along axis each displaced by 120 degrees, where x can be replaced with s or r to treat stator or rotor quantities (see *Figure 20*); supposing f_{qx}, f_{dx}, f_{0x} are their transformations, directed along

paths orthogonal to each other; the equations of transformation to a reference frame (rotating at an arbitrary angular velocity ω) can be expressed as:

$$f_{qdox} = \begin{bmatrix} f_{qx} \\ f_{dx} \\ f_{0x} \end{bmatrix} = \frac{2}{3} \times \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} f_{ax} \\ f_{bx} \\ f_{cx} \end{bmatrix}$$

where θ is the angular displacement of the (q, d) reference frame at the time of observation, and θ_0 that displacement at t=0 (see *Figure 20*).

Figure 20. Transformation from an *abc* stationary frame to a rotating frame (q, d)



With Clark's transformation, stator currents i_{as} and i_{bs} (which are directed along axes each displaced by 120 degrees) are resolved into currents $i\alpha$ and $i\beta$ on a stationary reference frame (α β).

Appropriate substitution into the general equations (given above) yields:

$$i_\alpha = i_{as}$$

$$i_\beta = -\frac{i_{as} + 2i_{bs}}{\sqrt{3}}$$

In Park's change of variables, stator currents i_α and i_β, which belong to a stationary reference frame (α β), are resolved to a reference frame synchronous with the rotor and oriented so that the d-axis is aligned with the permanent magnets flux, so as to obtain i_{qs} and i_{ds}.

Consequently, with this choice of reference, we have:

$$i_{qs} = i_{\alpha}\cos\theta_r - i_{\beta}\sin\theta_r$$
$$i_{ds} = i_{\alpha}\sin\theta_r + i_{\beta}\cos\theta_r$$

On the other hand, reverse Park transformation takes back stator voltage v_q and v_d, belonging to a rotating frame synchronous and properly oriented with the rotor, to a stationary reference frame, so as to obtain v_{α} and v_{β}:

$$v_{\alpha} = v_{qs}\cos\theta_r + v_{ds}\sin\theta_r$$
$$v_{\beta} = -v_{qs}\sin\theta_r + v_{ds}\cos\theta_r$$

3.10.1 Circle limitation

As discussed above, FOC allows to separately control the torque and the flux of a 3-phase permanent magnet motor. After the two new values(v_d^* and v_q^*) of the stator voltage producing flux and torque components of the stator current, have been independently computed by flux and torque PIDs, it is necessary to saturate the magnitude of the resulting vector ($|\vec{v}^*|$) before passing them to the Reverse Park transformation and, finally, to the SVPWM block.

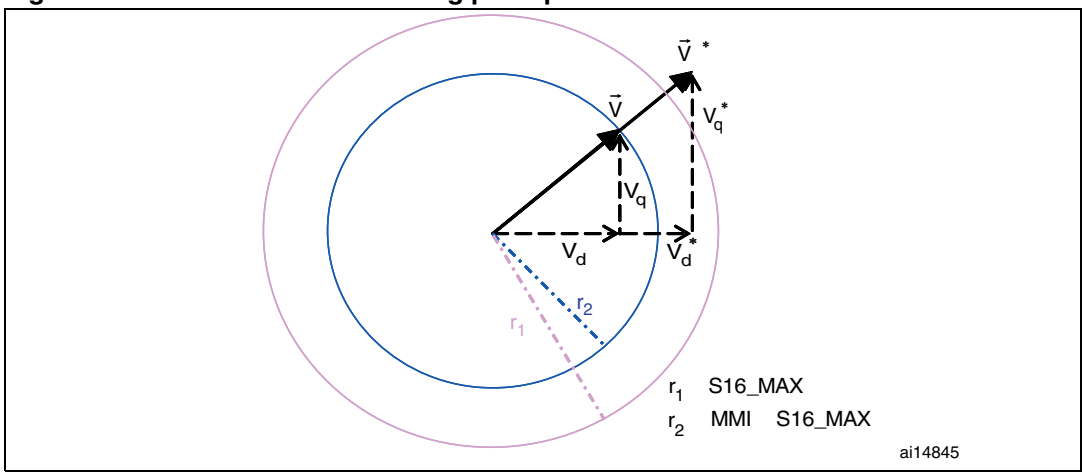
The saturation boundary is normally given by the value (S16_MAX=32767) which produces the maximum output voltage magnitude (corresponding to a duty cycle going from 0% to 100%).

Nevertheless, when using a single-shunt or three-shunt resistor configuration and depending on PWM frequency, it might be necessary to limit the maximum PWM duty cycle to guarantee the proper functioning of the stator currents reading block.

For this reason, the saturation boundary could be a value slightly lower than S16_MAX depending on PWM switching frequency when using a single-shunt or three-shunt resistor configuration.

The Circle Limitation function performs the discussed stator voltage components saturation, as illustrated in *Figure 21*.

Figure 21. Circle limitation working principle



V_d and V_q represent the saturated stator voltage components to be passed to the Reverse Park transformation function, while V_d^* and $V_q^*$are the outputs of the PID current controllers. From geometrical considerations, it is possible to draw the following relationship:

$$v_d = \frac{v_d^* \cdot MMI \cdot S16\_MAX}{\left|\vec{v}^*\right|}$$

$$v_q = \frac{v_q^* \cdot MMI \cdot S16\_MAX}{\left|\vec{v}^*\right|}$$

In order to speed up the computation of the above equations while keeping an adequate resolution, the value

$$\frac{MMI \cdot S16\_MAX^2}{\left|\vec{v}^*\right|}$$

is computed and stored in a look-up table for different values of $\left|\vec{v}^*\right|$ and MMI (Maximum Modulation Index).

4 Current sampling

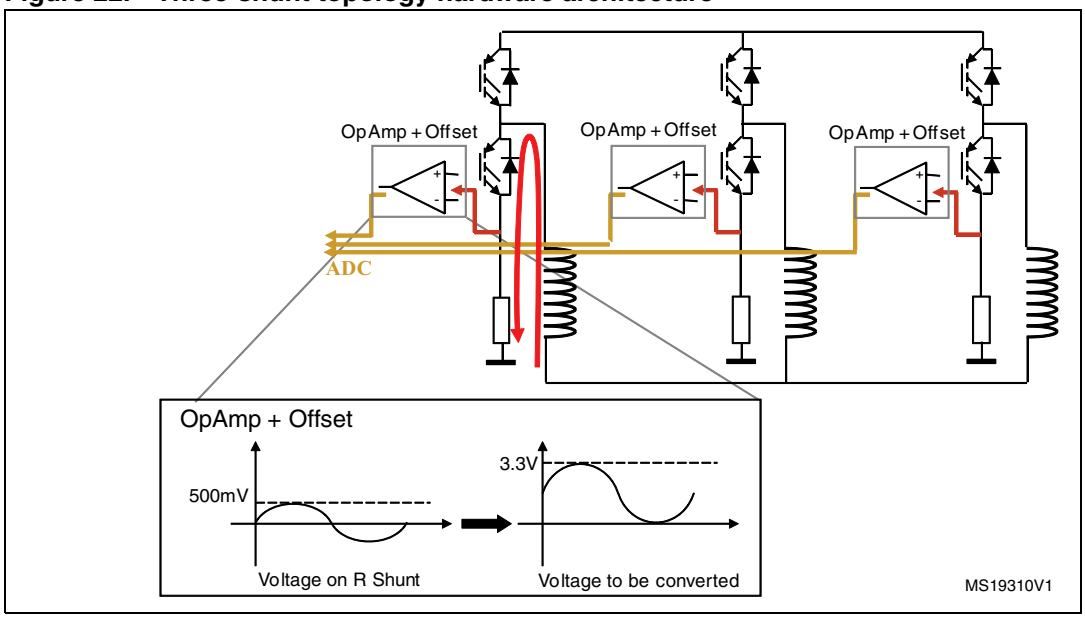
Section 3.1: Introduction to the PMSM FOC drive shows that current sampling plays a crucial role in PMSM field oriented control. This Motor Control Library provides complete modules for supporting three-shunt, single-shunt, and ICS topologies. Refer to sections *Section 4.1*, *Section 4.2*, *Section 5* respectively for further detail.

The selection of decoding algorithm—to match the topology actually in use—can be performed through correct settings in the.h parameter files (generated by the ST MC Workbench GUI) used to initialize the MC Application during its boot stage.

4.1 Current sampling in three shunt topology

Figure 22 shows the three-shunt topology hardware architecture.

Figure 22. Three-shunt topology hardware architecture



The three currents I_1, I_2, and I_3 flowing through a three-phase system follow the mathematical relation:

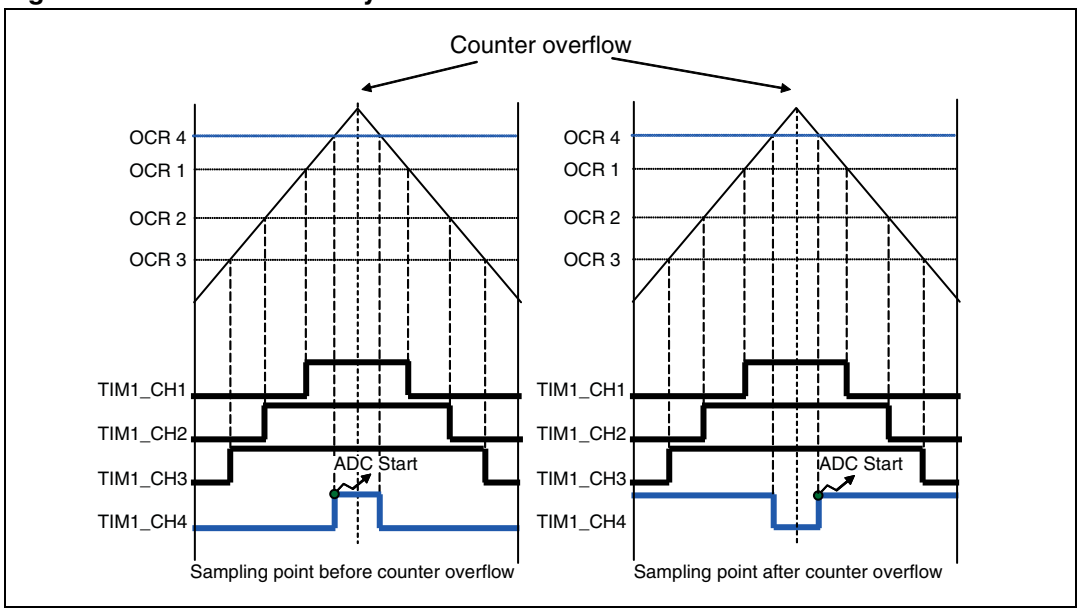
$$I_1 + I_2 + I_3 = 0$$

For this reason, to reconstruct the currents flowing through a generic three-phase load, it is sufficient to sample only two out of the three currents while the third one can be computed by using the above relation.

The flexibility of the Root part number 1 A/D converter makes it possible to synchronously sample the two A/D conversions needed for reconstructing the current flowing through the motor. The ADC can also be used to synchronize the current sampling point with the PWM output using the external triggering capability of the peripheral. Owing to this, current conversions can be performed at any given time during the PWM period. To do this, the control algorithm uses the fourth PWM channel of TIM1 to synchronize the start of the conversions.

Figure 23 shows the synchronization strategy between the TIM1 PWM output and the ADC. The A/D converter peripheral is configured so that it is triggered by the rising edge of TIM1_CH4.

Figure 23. PWM and ADC synchronization



In this way, supposing that the sampling point must be set before the counter overflow, that is, when the TIM1 counter value matches the OCR4 register value during the upcounting, the A/D conversions for current sampling are started. If the sampling point must be set after the counter overflow, the PWM 4 output has to be inverted by modifying the CC4P bit in the TIM1_CCER register. In so doing, when the TIM1 counter matches the OCR4 register value during the downcounting, the A/D samplings are started.

After execution of the FOC algorithm, the value to be loaded into the OCR4 register is calculated to set the sampling point for the next PWM period, and the A/D converter is configured to sample the correct channels.

Table 3. 3-shunt current reading, used resources (single drive, F103 LD/MD)

Adv. timer	DMA	ISR	ADC master	ADC slave	Note
TIM1	DMA1_CH5	None	ADC1	ADC2	DMA is used to enable ADC injected conversion external trigger. Disabling is performed by software.

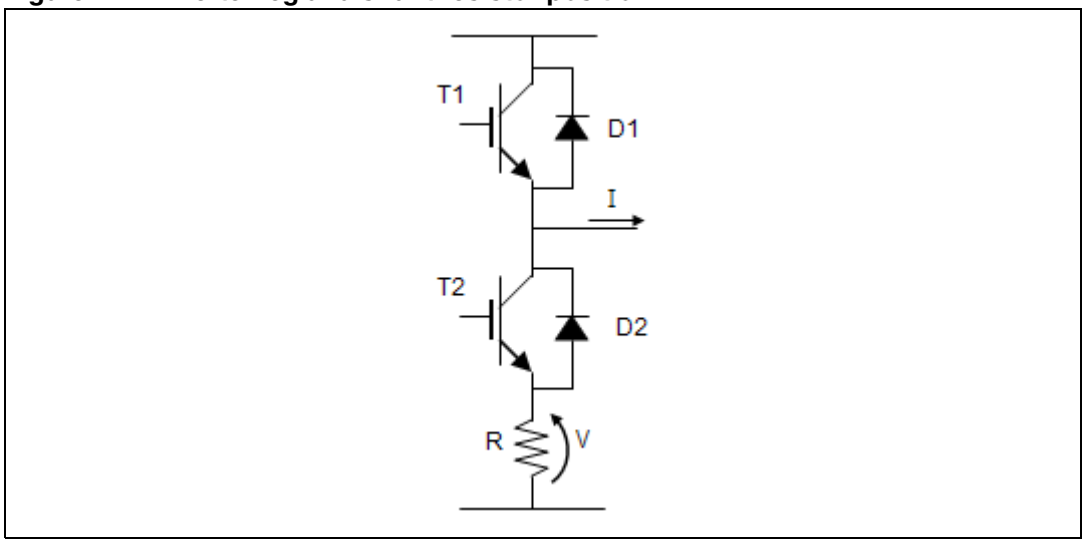
Table 4. 3-shunt current reading, used resources (single drive, or dual drive, F103 HD)

Adv. timer	DMA	ISR	ADC	Note
TIM1	None	TIM1_UP	ADC1 ADC2	Used by first or second motor configured in three shunt, according to user selection. ADC is used in time sharing. Trigger selection is performed in the TIM_UP ISR.
TIM8	None	TIM8_UP	ADC1 ADC2	used by first or second motor configured in three shunt, according to user selection. ADC is used in time sharing. Trigger selection is performed in the TIM_UP ISR.

4.1.1 Tuning delay parameters and sampling stator currents in three shunt resistor topology

Figure 24 shows one of the three inverter legs with the related shunt resistor:

Figure 24. Inverter leg and shunt resistor position



To indirectly measure the phase current I, it is possible to read the voltage V providing that the current flows through the shunt resistor R.

It is possible to demonstrate that, whatever the direction of current I, it always flows through the resistor R if transistor T2 is switched on and T1 is switched off. This implies that in order to properly reconstruct the current flowing through one of the inverter legs, it is necessary to properly synchronize the conversion start with the generated PWM signals. This also means that current reading cannot be performed on a phase where the duty cycle applied to the low side transistor is either null or very short.

Fortunately, as discussed in *Section 4.1*,to reconstruct the currents flowing through a generic three-phase load, it is sufficient to simultaneously sample only two out of three currents, the third one being computed from the relation given in *Section 4.1*. Thus, depending on the space vector sector, the A/D conversion of voltage V will be performed only on the two phases where the duty cycles applied to the low side switches are the highest. In particular, by looking at *Figure 19*, you can deduct that in sectors 1 and 6, the

voltage on the Phase A shunt resistor can be discarded; likewise, in sectors 2 and 3 for Phase B, and finally in sectors 4 and 5 for Phase C.

Moreover, in order to properly synchronize the two stator current reading A/D conversions, it is necessary to distinguish between the different situations that can occur depending on PWM frequency and applied duty cycles.

Note: The explanations below refer to space vector sector 4. They can be applied in the same manner to the other sectors.

Case 1: Duty cycle applied to Phase A low side switch is larger than DT+T_N

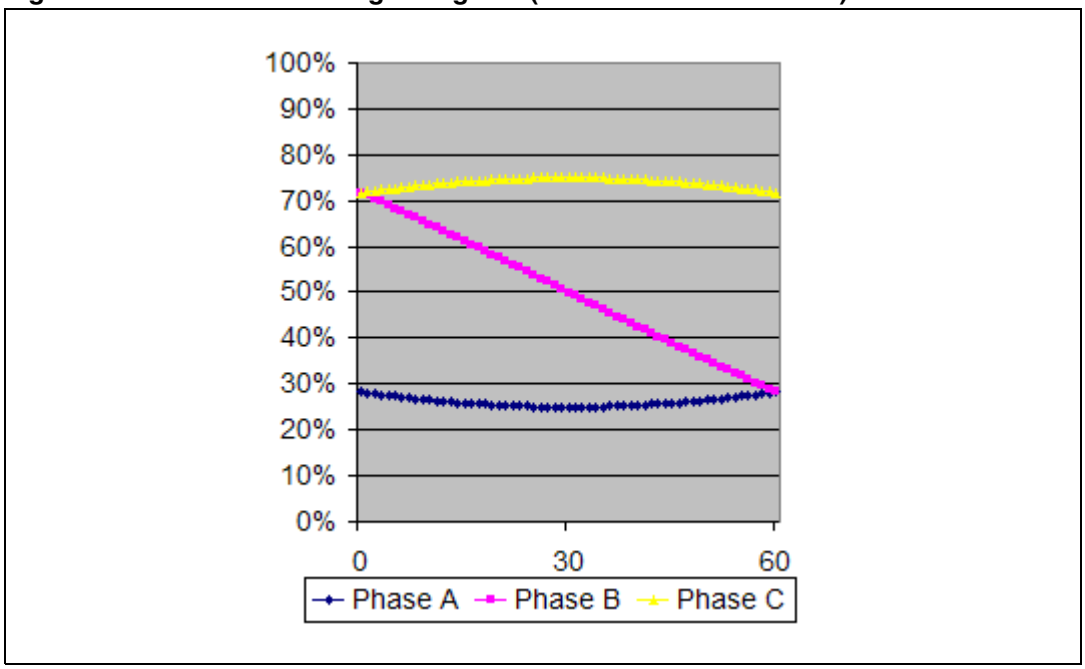
Where:

- DT is dead time.
- T_N is the duration of the noise induced on the shunt resistor voltage of a phase by the commutation of a switch belonging to another phase.
- T_S is the sampling time of the Root part number 1 A/D converter (the following consideration is made under the hypothesis that T_S < DT + T_N). Refer to the Root part number 1 reference manual for more detailed information.

This case typically occurs when SVPWM with low (<60%) modulation index is generated (see *Figure 25*). The modulation index is the applied phase voltage magnitude expressed as a percentage of the maximum applicable phase voltage (the duty cycle ranges from 0% to 100%).

Figure 26 offers a reconstruction of the PWM signals applied to low side switches of Phase A and B in these conditions plus a view of the analog voltages measured on the Root part number 1 A/D converter pins for both Phase B and C (the time base is lower than the PWM period).

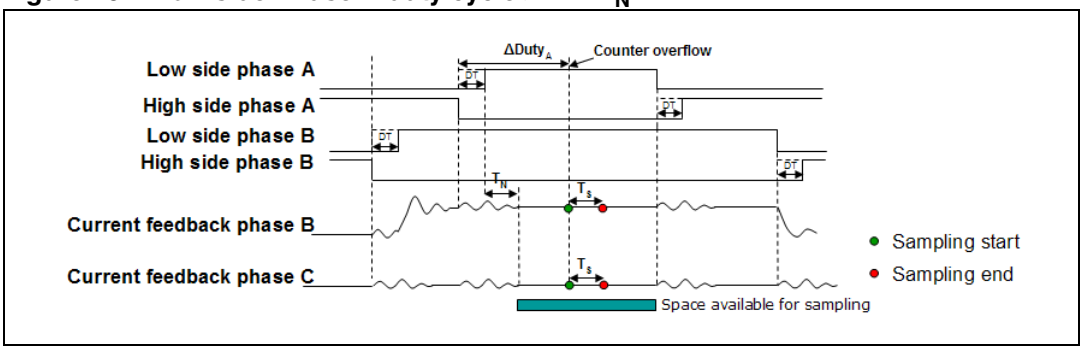
Figure 25. Low-side switch gate signals (low modulation indexes)



Note that these current feedbacks are constant in the view in *Figure 26* because it is assumed that commutations on Phase B and C have occurred out of the visualized time window.

Moreover, it can be observed that in this case the two stator current sampling conversions can be performed synchronized with the counter overflow, as shown in *Figure 26*.

Figure 26. Low side Phase A duty cycle > DT+T_N



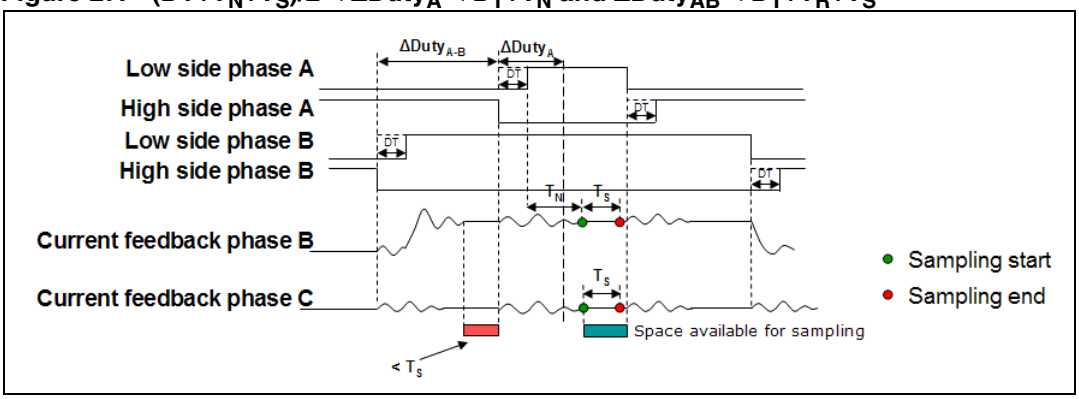
Case 2: (DT+T_N+T_S)/2 < ΔDuty$_A$ < D_T+T_N and ΔDuty$_{AB}$ < D_T+T_R+T_S

With the increase in modulation index, ΔDuty$_A$ can have values smaller than D_T+T_N. Sampling synchronized with the counter overflow could be impossible.

In this case, the two currents can still be sampled between the two Phase A low side commutations, but only after the counter overflow.

Consider that in order to avoid the acquisition of the noise induced on the phase B current feedback by phase A switch commutations, it is required to wait for the noise to be over (T_N). See *Figure 27*.

Figure 27. (DT+T_N+T_S)/2 < ΔDuty$_A$ < D_T+T_N and ΔDuty$_{AB}$ < D_T+T_R+T_S

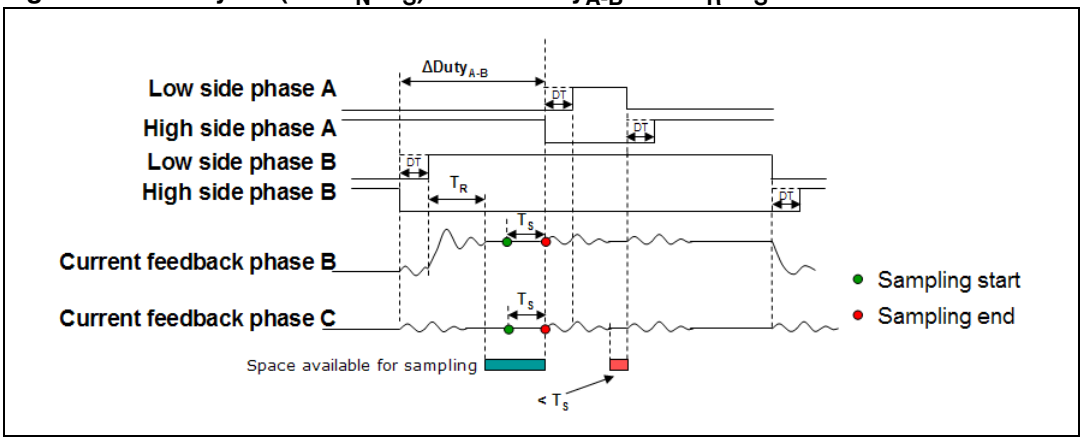


Case 3: ΔDutyA < (DT+T_N+T_S)/2 and ΔDuty$_{A-B}$>DT+T_R+T_S

In this case, it is no more possible to sample the currents during Phase A low-side switch-on. Anyway, the two currents can be sampled between Phase B low-side switch-on and

Phase A high-side switch-off. The choice was therefore made to sample the currents T_S µs before of phase A high-side switch-off (see *Figure 28*).

Figure 28. $\Delta DutyA < (DT+T_N+T_S)/2$ and $\Delta Duty_{A-B}>DT+T_R+T_S$



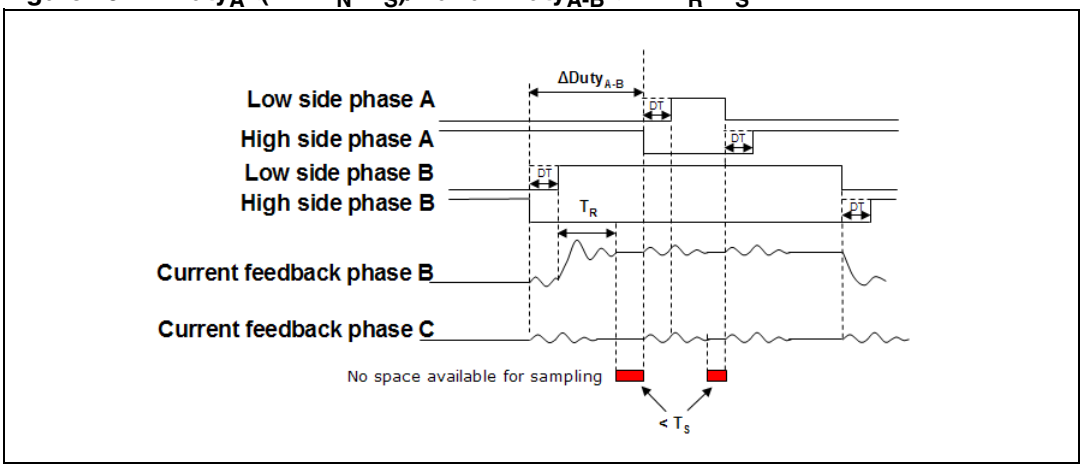
Case 4: $\Delta Duty_A<(DT+T_N+T_S)/2$ and $\Delta Duty_{A-B}<DT+T_R+T_S$

In this case, the duty cycle applied to Phase A is so short that no current sampling can be performed between the two low-side commutations.

Furthermore if the difference in duty cycles between Phases B and A is not long enough to allow the A/D conversions to be performed between Phase B low-side switch-on and Phase A high-side switch-off, it is impossible to sample the currents (See *Figure 29*).

To avoid this condition, it is necessary to reduce the maximum modulation index or decrease the PWM frequency.

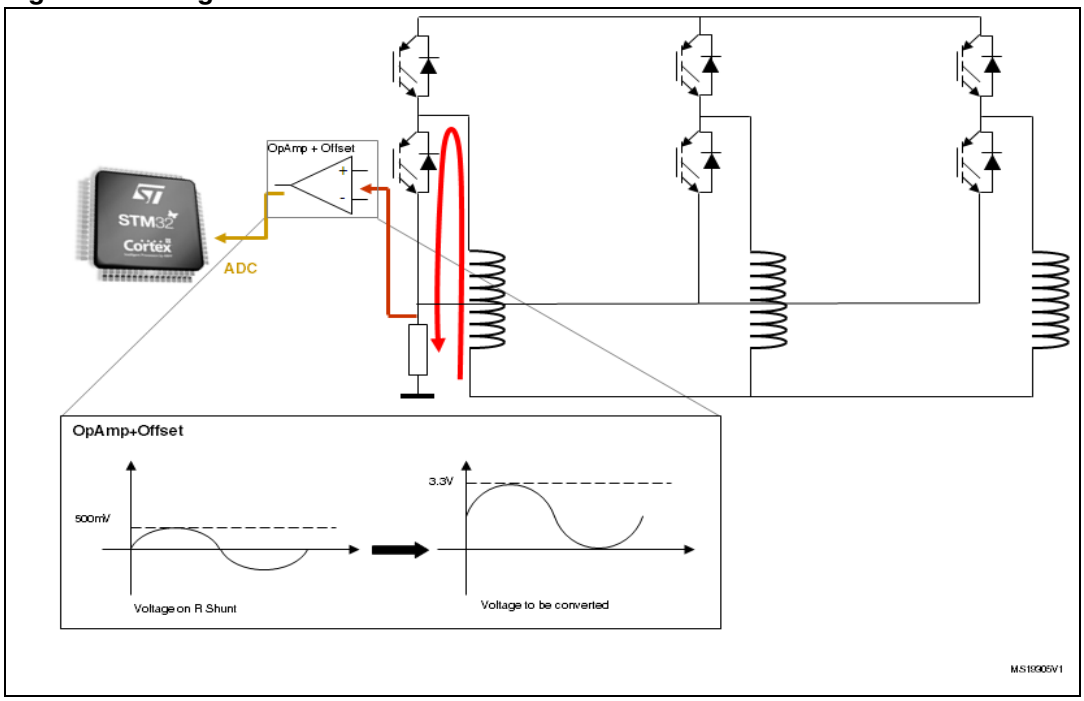
Figure 29. $\Delta Duty_A<(DT+T_N+T_S)/2$ and $\Delta Duty_{A-B}<DT+T_R+T_S$



4.2 Current sampling in single-shunt topology

Figure 30 illustrates the single-shunt topology hardware architecture.

Figure 30. Single-shunt hardware architecture



It is possible to demonstrate that for each configuration of the low-side switches, the current through the shunt resistor is given in *Table 5*. T_4, T_5 and T_6 assume the complementary values of T_1, T_2 and T_3, respectively.

In *Table 5*, the value “0” means that the switch is open whereas the value “1” means that the switch is closed.

Table 5. Current through the shunt resistor

T_1	T_2	T_3	I_{Shunt}
0	0	0	0
0	1	1	i_A
0	0	1	$-i_C$
1	0	1	i_B
1	0	0	$-i_A$
1	1	0	i_C
0	1	0	$-i_B$
1	1	1	0

Using the centered-aligned pattern, each PWM period is subdivided into 7 subperiods (see *Figure 31*). During three subperiods (I, IV, VII) the current through the shunt resistor is zero. During the other subperiods, the current through the shunt resistor is symmetrical with respect to the center of the PWM.

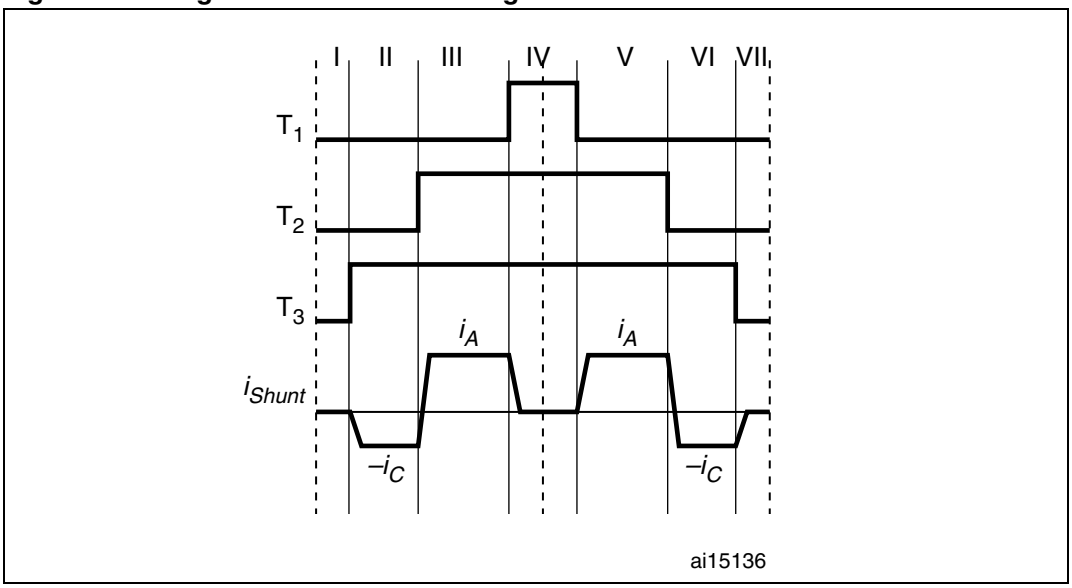
For the conditions showed in *Figure 31*, there are two pairs:

- subperiods II and VI, during which i_{Shunt} is equal to $-i_C$
- subperiods III and V, during which i_{Shunt} is equal to i_A

So under these conditions, it is possible to reconstruct the three-phase current through the motor from the sampled values:

- i_A is i_{Shunt} measured during subperiod III or V
- i_C is $-i_{Shunt}$ measured during subperiod II or VI
- $i_B = -i_A - i_C$

Figure 31. Single-shunt current reading



But if the stator-voltage demand vector lies in the boundary space between two space vector sectors, two out of the three duty cycles will assume approximately the same value. In this case, the seven subperiods are reduced to five subperiods.

Under these conditions, only one current can be sampled, the other two cannot be reconstructed. This means that it is not possible to sense both currents during the same PWM period, when the imposed voltage demand vector falls in the gray area of the space vector diagram represented in *Figure 31: Single-shunt current reading*.

Table 6. Single shunt current reading, used resources (single drive, F103/F100 LD/MD)

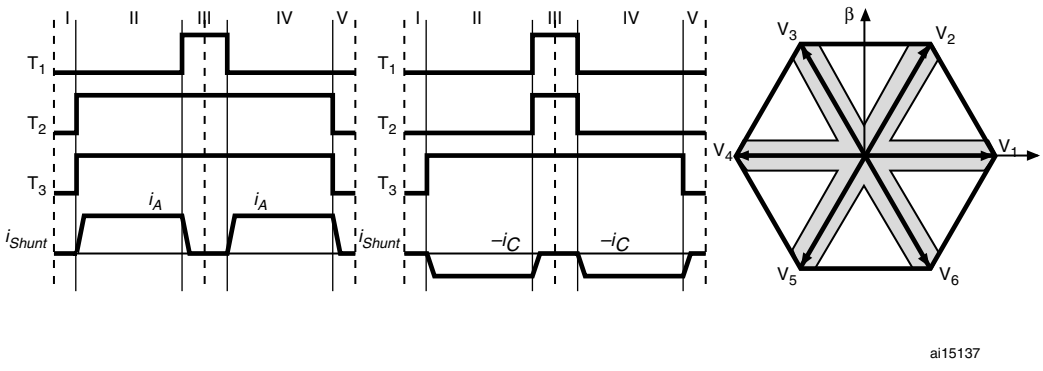
Adv. timer	Aux. timer	DMA	ISR	ADC	Note
TIM1	TIM3 (CH4)	DMA1_CH3 DMA1_CH4	TIM1_UP DMA1_CH4_TC (Rep>1)	ADC1	LD device configuration, RC DAC cannot be used
TIM1	TIM4 (CH3)	DMA1_CH5 DMA1_CH4	TIM1_UP DMA1_CH4_TC (Rep>1)	ADC1	MD device configuration

Table 7. Single shunt current reading, used resources (single or dual drive, F103HD)

Adv. timer	Aux. timer	DMA	ISR	ADC	Note
TIM1	TIM5 (CH4)	DMA2_CH1 DMA1_CH4	TIM1_UP DMA1_CH4_TC (Rep>1)	ADC3	Option1: used by the first motor configured in single shunt, or the second motor when the first is not single shunt.
TIM8	TIM4 (CH3)	DMA1_CH5 DMA2_CH2	TIM8_UP DMA2_CH2_TC (Rep>1)	ADC1	Option1: used by the second motor configured in single shunt when the first motor is also configured in single shunt.
TIM8	TIM5 (CH4)	DMA2_CH1 DMA2_CH2	TIM8_UP DMA2_CH2_TC (Rep>1)	ADC3	Option2: used by the first motor configured in single shunt or by the second motor when the first is not single shunt.
TIM1	TIM4 (CH3)	DMA1_CH5 DMA1_CH4	TIM1_UP DMA1_CH4_TC (Rep>1)	ADC1	Option2: used by the second motor configured in single shunt when the first motor is also configured in single shunt.

Using F103HD in single drive, it is possible to choose between option 1 and option 2 (*Table 7*); resources are allocated or saved accordingly.

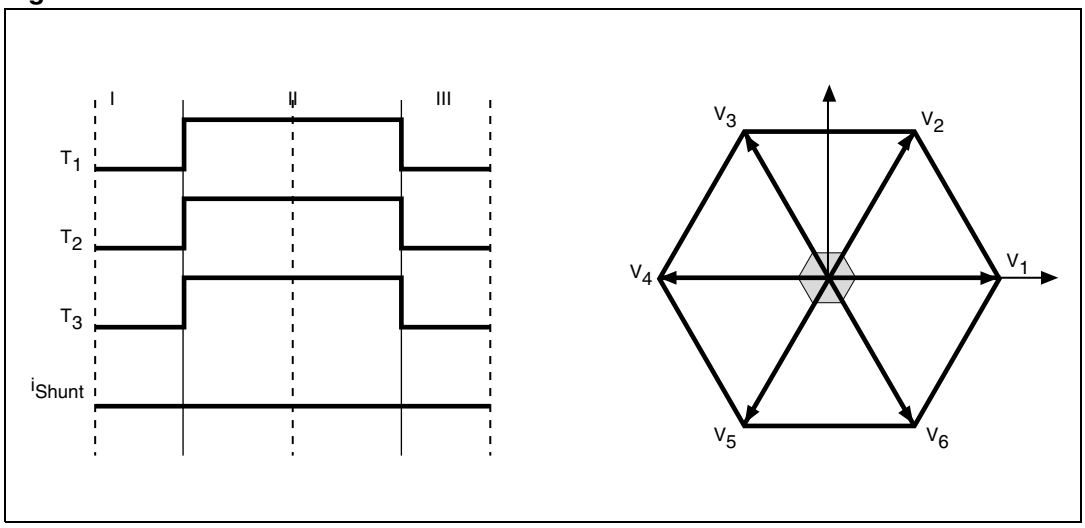
Figure 32. Boundary between two space-vector sectors



Similarly, for a low modulation index, the three duty cycles assume approximately the same value. In this case, the seven subperiods are reduced to three subperiods. During all three

subperiods, the current through the shunt resistor is zero. This means that it is not possible to sense any current when the imposed voltage vector falls in the gray area of the space-vector diagram represented in *Figure 33*.

Figure 33. Low modulation index



4.2.1 Definition of the noise parameter and boundary zone

T_{Rise} is the time required for the data to become stable in the ADC channel after the power device has been switched on or off.

The duration of the ADC sampling is called the sampling time.

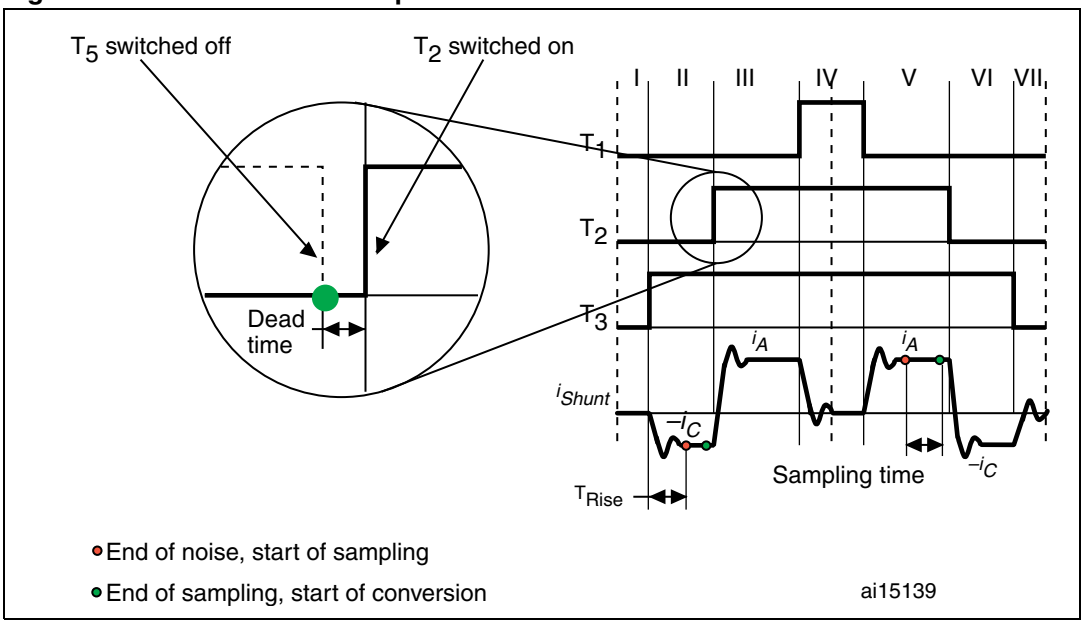
T_{MIN} is the minimum time required to perform the sampling, and

$$T_{MIN} = T_{Rise} + \text{sampling time} + \text{dead time}$$

D_{MIN} is the value of T_{MIN} expressed in duty cycle percent. It is related to the PWM frequency as follows:

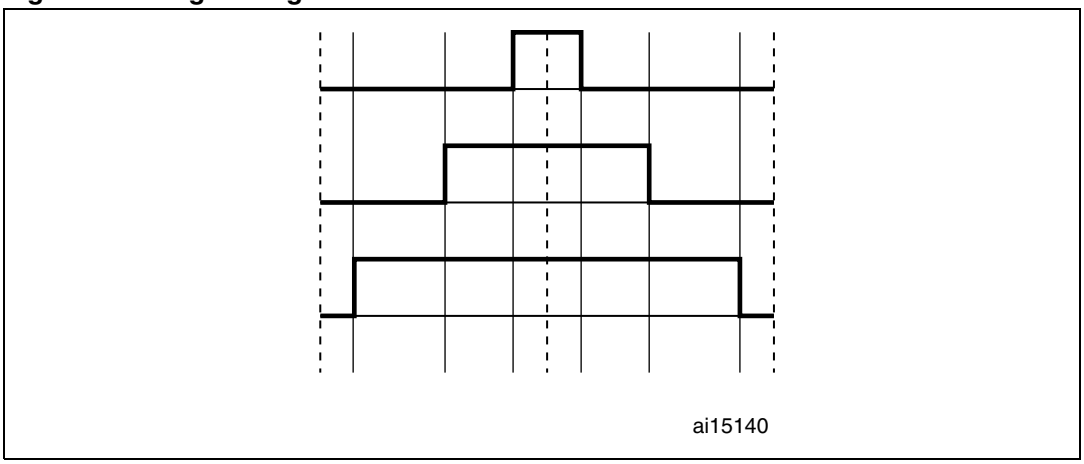
$$D_{MIN} = (T_{MIN} \times F_{PWM}) \times 100$$

Figure 34. Definition of noise parameters



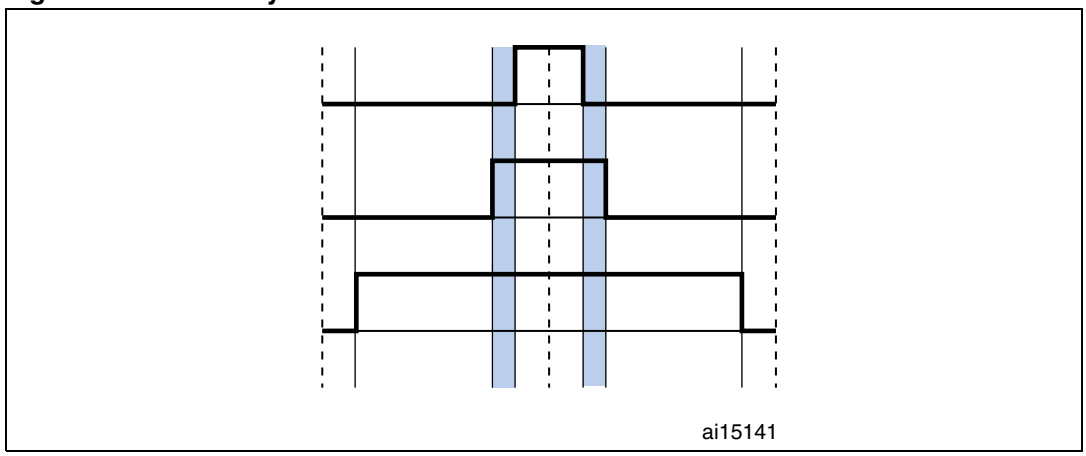
The voltage-demand vector lies in a region called the Regular region when the three duty cycles (calculated by space vector modulation) inside a PWM pattern differ from each other by more than D_{MIN}. This is represented in *Figure 35*.

Figure 35. Regular region



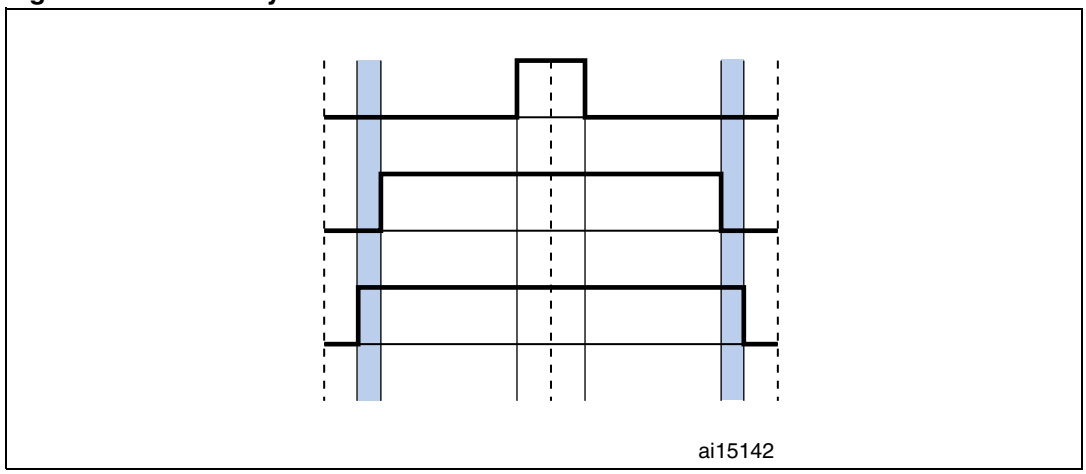
The voltage-demand vector lies in a region called Boundary 1 when two of the duty cycles differ from each other by less than D_{MIN}, and the third is greater than the other two and differs from them by more than D_{MIN}. This is represented in *Figure 36*.

Figure 36. Boundary 1



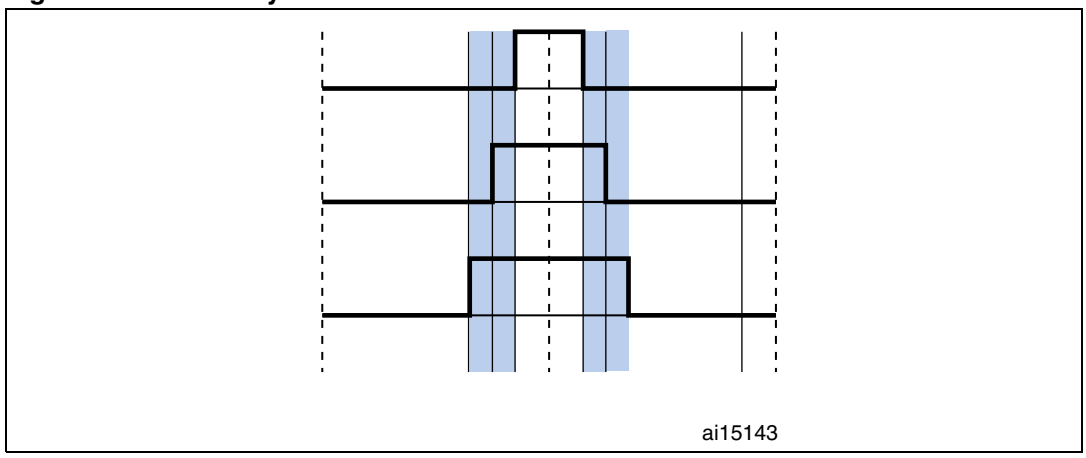
The voltage-demand vector lies in a region called Boundary 2 when two duty cycles differ from each other by less than D_{MIN}, and the third is smaller than the other two and differs from them by more than D_{MIN}. This is represented in *Figure 37*.

Figure 37. Boundary 2



The voltage-demand vector lies in a region called Boundary 3 when the three PWM signals differ from each other by less than D_{MIN}. This is represented in *Figure 38*.

Figure 38. Boundary 3



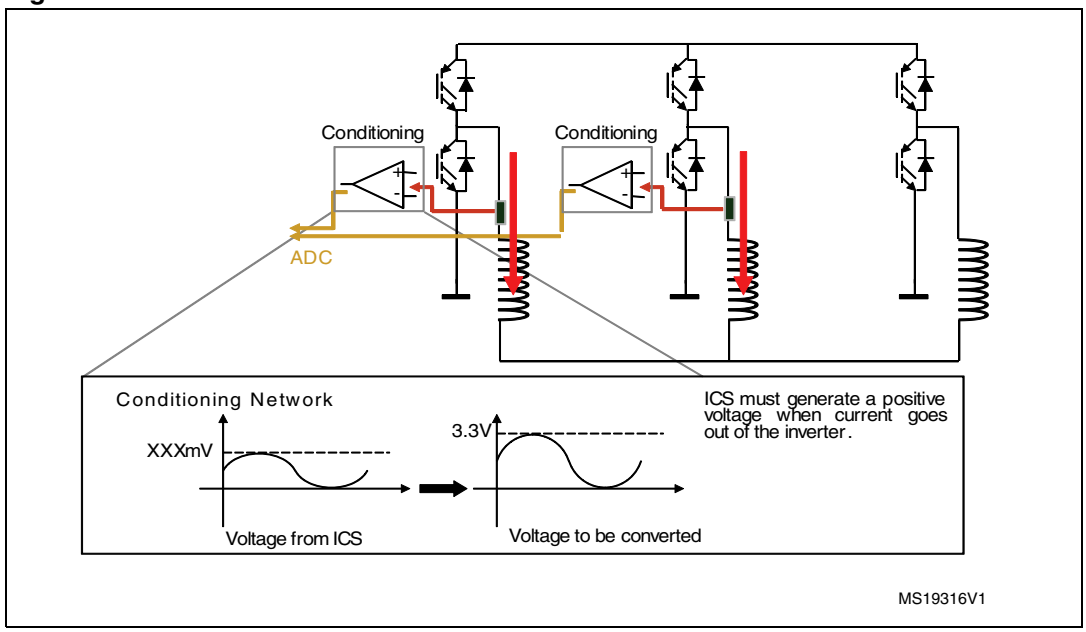
If the voltage-demand vector lies in Boundary 1 or Boundary 2 region, a distortion must be introduced in the related PWM signal phases to sample the motor phase current.

An ST patented technique for current sampling in the “Boundary” regions has been implemented in the firmware. Please contact your nearest ST sales office or support team for further information about this technique.

4.3 Current sampling in isolated current sensor topology

Figure 39 illustrates the ICS topology hardware architecture.

Figure 39. ICS hardware architecture



The three currents I_1, I_2, and I_3 flowing through a three-phase system follow the mathematical relationship:

$$I_1 + I_2 + I_3 = 0$$

Table 8. ICS current reading, used resources (single drive, F103 LD/MD)

Adv. timer	DMA	ISR	ADC master	ADC slave	Note
TIM1	DMA1_CH5	None	ADC1	ADC2	DMA is used to enable ADC injected conversion external trigger. Disabling is performed by software.

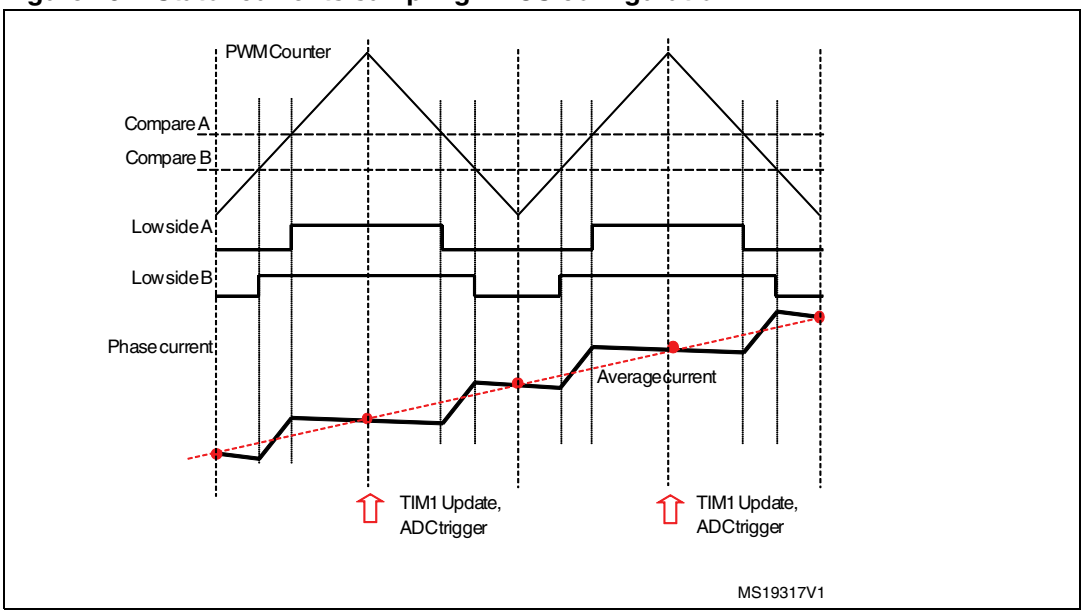
Table 9. ICS current reading, used resources (single or dual drive, F103 HD)

Adv. timer	DMA	ISR	ADC	Note
TIM1	None	TIM1_UP	ADC1 ADC2	Used by the first or second motors configured in three shunt, depending on the user selection. ADC is used in time sharing. Trigger selection is performed in the TIM_UP ISR.
TIM8	None	TIM8_UP	ADC1 ADC2	Used by the first or second motors configured in three shunt, depending on the user selection. ADC is used in time sharing. Trigger selection is performed in the TIM_UP ISR.

Therefore, to reconstruct the currents flowing through a generic three-phase load, it is sufficient to sample only two out of the three currents while the third one can be computed by using the above relationship.

The flexibility of the Root part number 1 A/D converter trigger makes it possible to synchronize the two A/D conversions necessary for reconstructing the stator currents flowing through the motor with the PWM reload register updates. This is important because, as shown in *Figure 40*, it is precisely during counter overflow and underflow that the average level of current is equal to the sampled current. Refer to the Root part number 1 reference manual to learn more about A/D conversion triggering.

Figure 40. Stator currents sampling in ICS configuration



5 Rotor position / speed feedback

Section 3.1: Introduction to the PMSM FOC drive shows that rotor position / speed measurement has a crucial role in PMSM field oriented control. Hall sensors or encoders are broadly used in the control chain for that purpose. Sensorless algorithms for rotor position / speed feedback are considered very useful for various reasons: to lower the overall cost of the application, to enhance the reliability by redundancy, and so on. Refer to *Section 5.1: The sensorless algorithm*, *Section 5.2: Hall sensor feedback processing*, and *Section 5.3: Encoder sensor feedback processing* for further detail.

The selection of speed/position feedback can be performed through correct settings in the.h parameter files (generated by the ST MC Workbench GUI) used to initialize the MC Application during its boot stage.

5.1 The sensorless algorithm

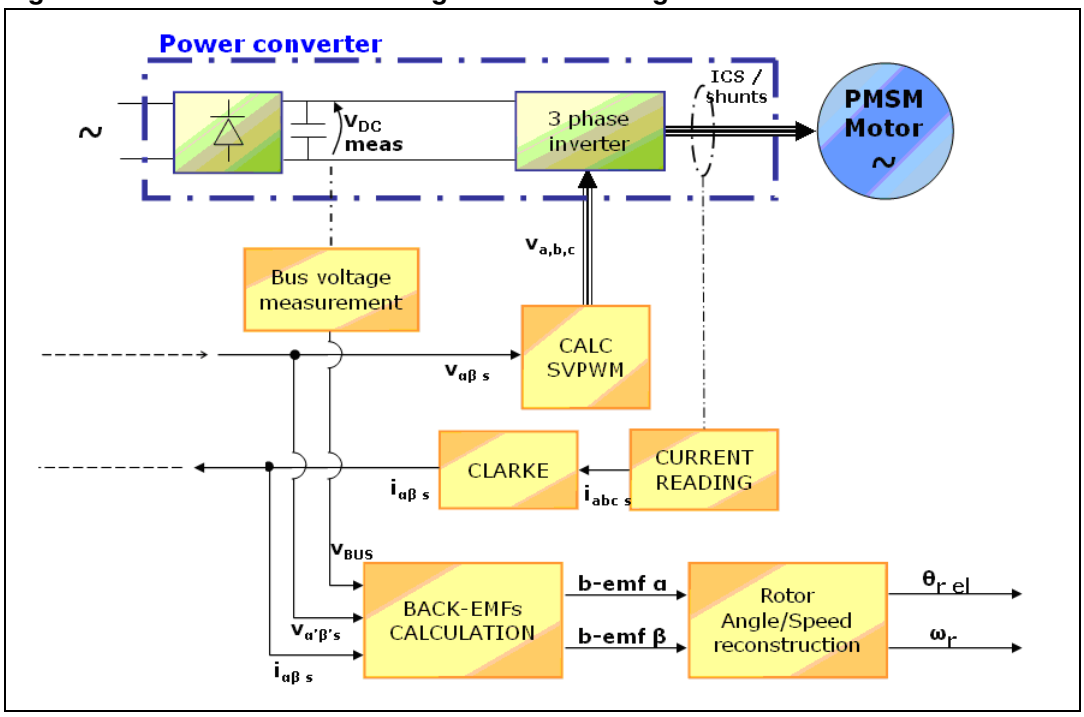
This firmware library provides a complete solution for sensorless detection of rotor position / speed feedback, which is based on the state observer theory. The implemented algorithm is applicable to both SM-PM and IPM synchronous motors, as explained in [5] (Appendix *Section A.1: References*). A theoretical and experimental comparison between the implemented rotor flux observer and a classical VI estimator [6](Appendix *Section A.1: References*) has pointed out the observer's advantage, which turns out to be a clearly reduced dependence on the stator resistance variation and an overall robustness in terms of parameter variations.

A state observer, in control theory, is a system that provides an estimation of the internal state of a real system, given its input and output measurement.

In our case, the internal states of the motor are the back-emfs and the phase currents, while the input and output quantities supplied are the phase voltages and measured currents, respectively (see *Figure 11*).

DC bus voltage measurement is used to convert voltage commands into voltage applied to motor phases.

Figure 41. General sensorless algorithm block diagram



The observed states are compared for consistency with the real system via the phase currents, and the result is used to adjust the model through a gain vector (K1, K2).

The motor back-emfs are defined as:

$$e_\alpha = \Phi_m p\omega_t \cos(p\omega_t t)$$
$$e_\beta = -\Phi_m p\omega_t \sin(p\omega_t t)$$

As can be seen, they hold information about the rotor angle. Then, back-emfs are fed to a block which is able to reconstruct the rotor electrical angle and speed. This latter block can be a PLL (Phase-Locked Loop) or a CORDIC (COordinate Rotation DIgital Computer), depending on the user's choice.

In addition, the module processes the output data and, by doing so, implements a safety feature that detects locked-rotor condition or malfunctioning.

Figure 42 shows a scope capture taken while the motor is running in field oriented control (positive rolling direction); the yellow and the red waveforms (C1,C2) are respectively the observed back-emfs alpha and beta, the blue square wave (C3) is a signal coming from a Hall sensor cell placed on the a-axis, the green sinewave is current i_a (C4).

In confidential distribution, the classes that implement the sensorless algorithm are provided as compiled object files. The source code is available free of charge from ST on request. Please contact your nearest ST sales office.

5.1.1 A priori determination of state observer gains

The computation of the initial values of gains K1 and K2 is based on the placement of the state observer eigenvalues. The required motor parameters are r_s (motor winding resistance), L_s (motor winding inductance), T (sampling time of the sensorless algorithm, which coincides with FOC and stator currents sampling).

The motor model eigenvalues could be calculated as:

$$e_1 = 1 - \frac{r_s T}{L_s}$$

$$e_2 = 1$$

The observer eigenvalues are placed with:

$$e_{1obs} = \frac{e_1}{f}$$

$$e_{2obs} = \frac{e_2}{f}$$

Typically, as a rule of the thumb, set $f = 4$;

The initial values of K1 and K2 could be calculated as:

$$K_1 = \frac{e_{1obs} + e_{2obs} - 2}{T} + \frac{r_s}{L_s}$$

$$K_2 = \frac{L_s(1 - e_{1obs} - e_{2obs} + e_{1obs}e_{2obs})}{T^2}$$

This procedure is followed by the ST MC Workbench GUI to calculate proper state observer gains. It is also possible to modify these values using other criteria or after fine-tuning.

Figure 42. PMSM back-emfs detected by the sensorless state observer algorithm

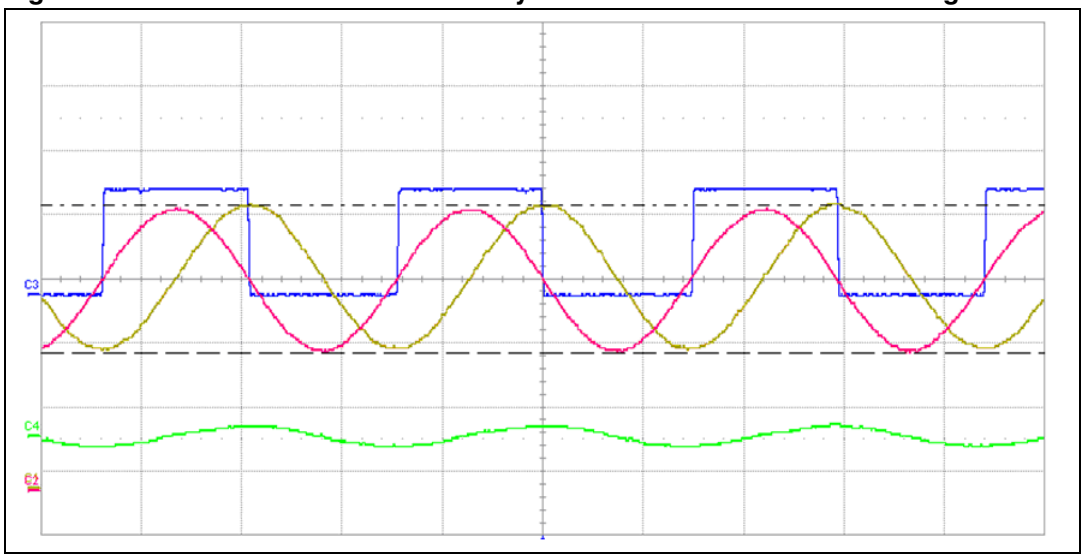


Table 10. Legend for *Figure 42*

Reference	Description
C1	b-emf alpha
C2	b-emf beta
C3	Hall 1
C4	phase A, measured current

More information on how to fine tune parameters to make the firmware suit the motor can be found in *Section 8: LCD user interface*.

5.2 Hall sensor feedback processing

5.2.1 Speed measurement implementation

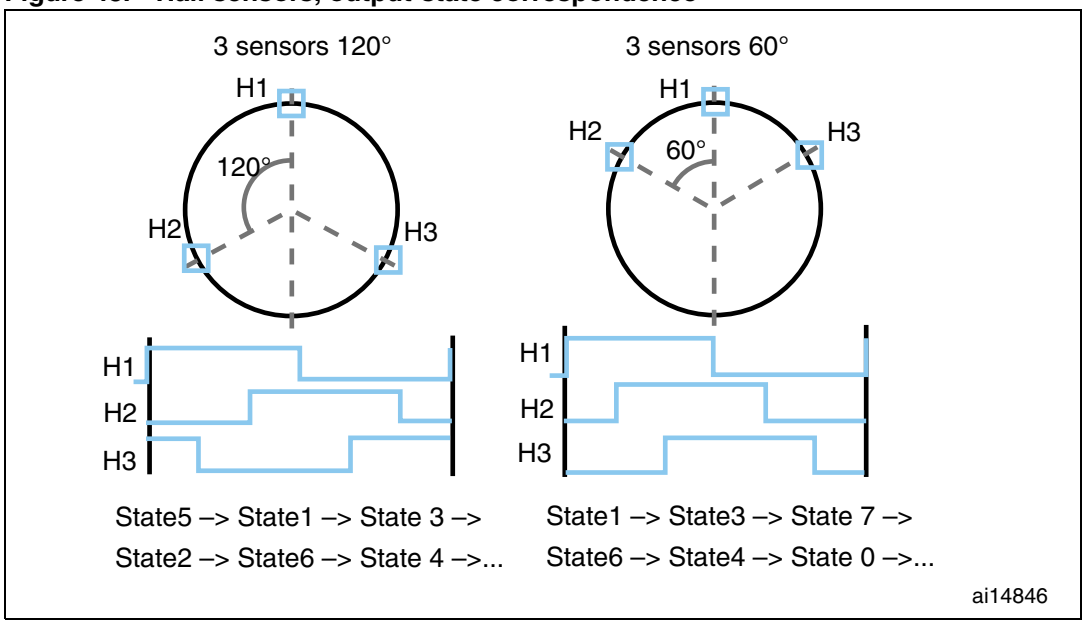
Thanks to the Root part number 1 / F100xx general-purpose timer (TIMx) features, it is very simple to interface the microcontroller with three Hall sensors. In fact, when the TI1S bit in the TIMx_CR2 register is set, the three signals on the TIMx_CH1, TIMx_CH2 and TIMx_CH3 pins are XORed and the resulting signal is input to the logic performing TIMx input capture.

In this way, the speed measurement is converted into the period measurement of a square wave with a frequency six times higher than the real electrical frequency. The only exception is that the rolling direction, which is not extractable from the XORed signal, is on the contrary performed by directly accessing the three Hall sensor outputs.

Rolling direction identification

As shown in *Figure 43*, it is possible to associate any of Hall sensor output combinations with a state whose number is obtainable by considering H3-H2-H1 as a three-digit binary number (H3 is the most significant bit).

Figure 43. Hall sensors, output-state correspondence



Consequently, it is possible to reconstruct the rolling direction of the rotor by comparing the present state with the previous one. In the presence of a positive speed, the sequence must be as illustrated in *Figure 43*.

Period measurement

Although the principle for measuring a period with a timer is quite simple, it is important to keep the best resolution, in particular for signals, such as the one under consideration, that can vary with a ratio that can easily reach 1:1000.

In order to always have the best resolution, the timer clock prescaler is constantly adjusted in the current implementation.

The basic principle is to speed up the timer if the captured values are too low (for an example of short periods, see *Figure 44*), and to slow it down when the timer overflows between two consecutive captures (see example of large periods in *Figure 45*).

Figure 44. Hall sensor timer interface prescaler decrease

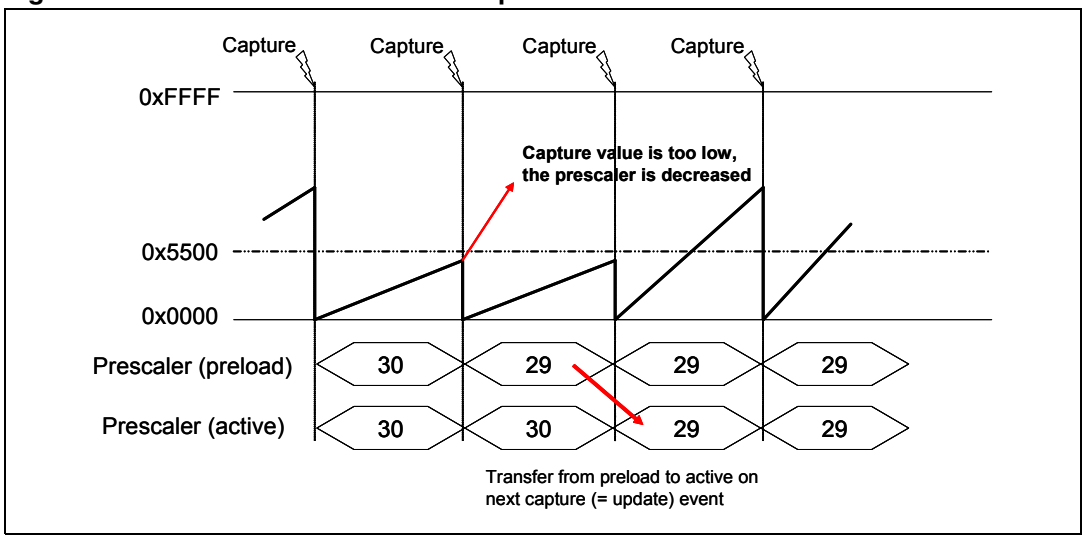
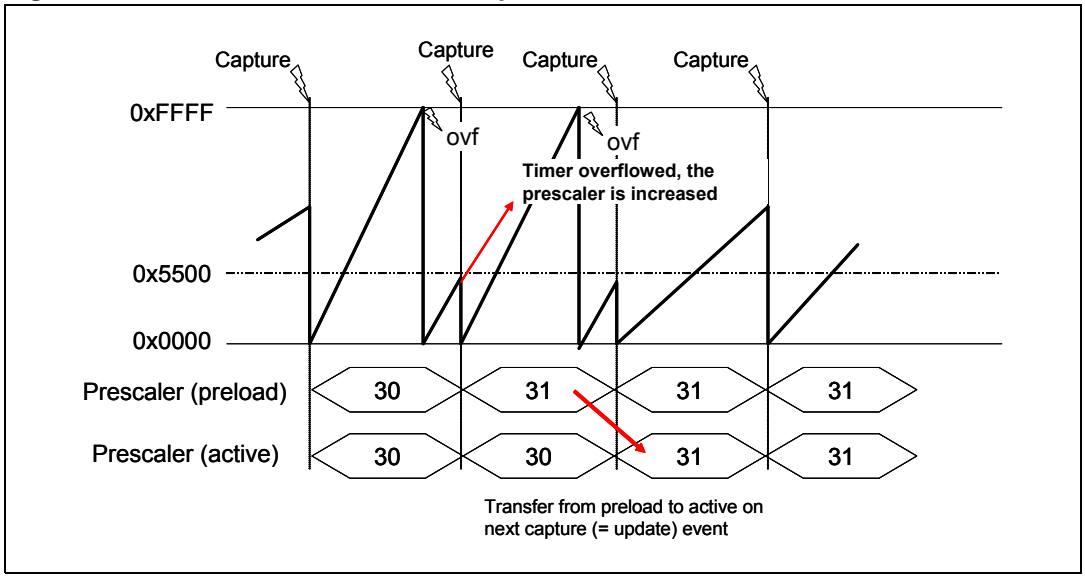


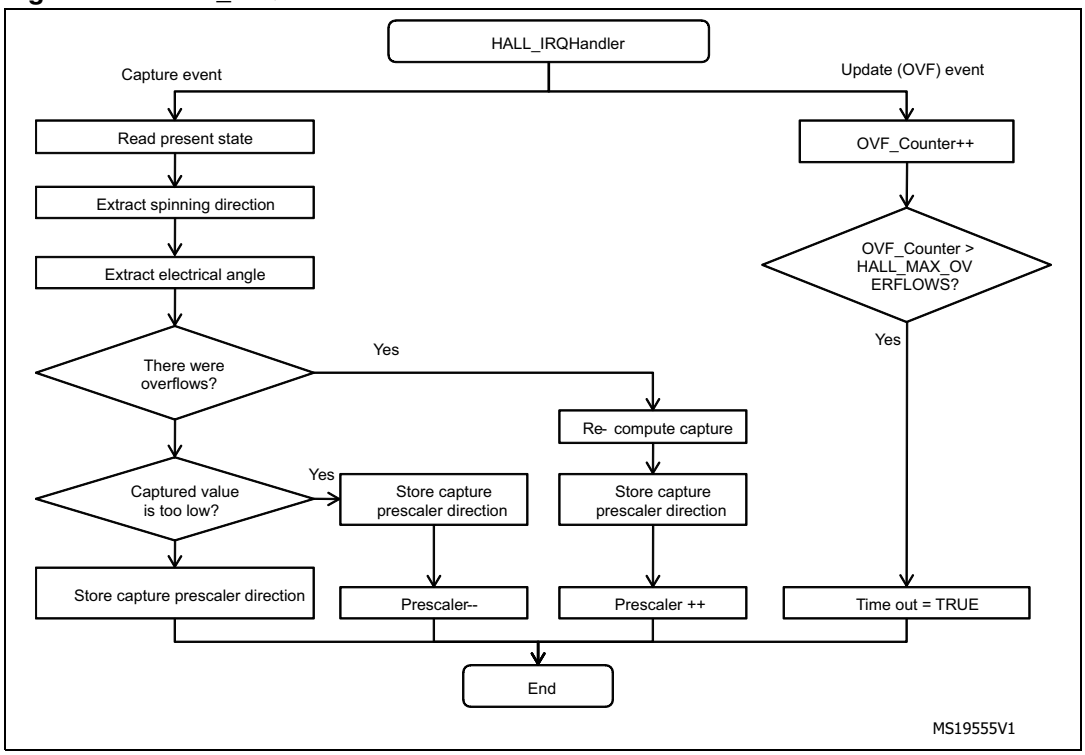
Figure 45. Hall sensor timer interface prescaler increase



The prescaler modification is done in the capture interrupt, taking advantage of the buffered registers: the new prescaler value is taken into account only on the next capture event, by the hardware, without disturbing the measurement.

Further details are provided in the flowchart shown in *Figure 46*, which summarizes the actions taken into the TIMx_IRQHandler.

Figure 46. TIMx_IRQHandler flowchart



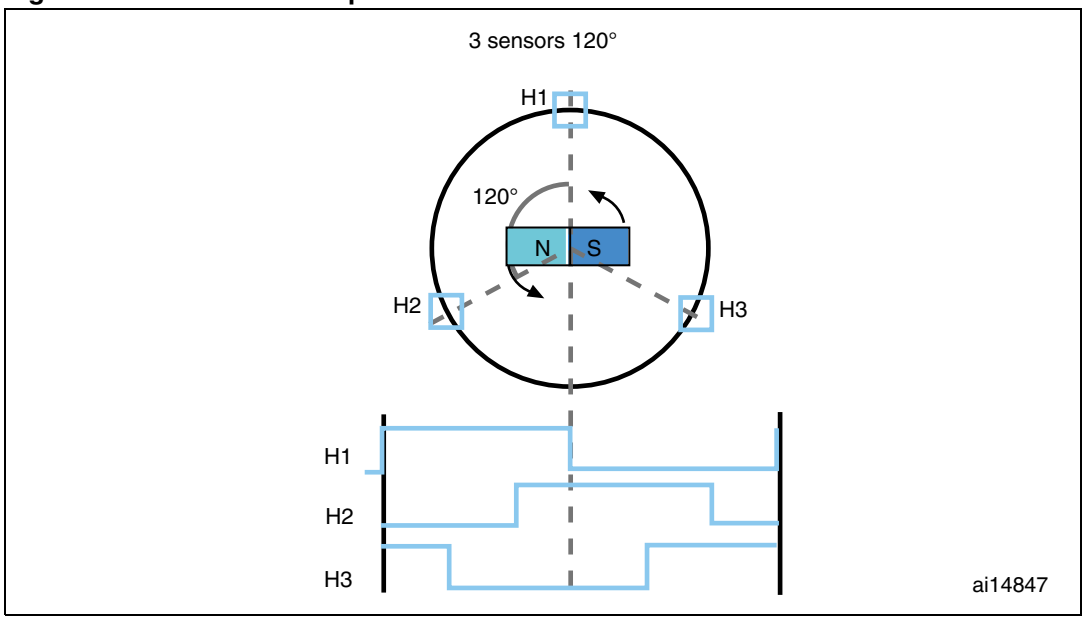
5.2.2 Electrical angle extrapolation implementation

As shown in *Figure 46*, the speed measurement is not the only task performed in TIMx_IRQHandler. As well as the speed measurement, the high-to-low or low-to-high transition of the XORed signal also gives the possibility of synchronizing the software variable that contains the present electrical angle.

Synchronization is performed avoiding abrupt changes in the measured electrical angles. In order to do this, the difference between the expected electrical angle, computed from the last speed measurement, and the real electrical angle, coming from the Hall sensor signals (see *Figure 66*) is computed. The new speed measurement is adjusted with this information in order to compensate the difference.

As can be seen in *Figure 47* any Hall sensor transition gives very precise information about rotor position.

Figure 47. Hall sensor output transitions



Furthermore, the utilisation of the FOC algorithm implies the need for a good and constant rotor position accuracy, including between two consecutive falling edges of the XORed signal (which occurs each 60 electrical degrees). For this reason it is clearly necessary to interpolate rotor electrical angle information. For this purpose, the latest available speed measurement (see *Section 7.4: Measurement units*) in dpp format (adjusted as described above) is added to the present electrical angle software variable value any time the FOC algorithm is executed. See *Section 7.4: Measurement units*.

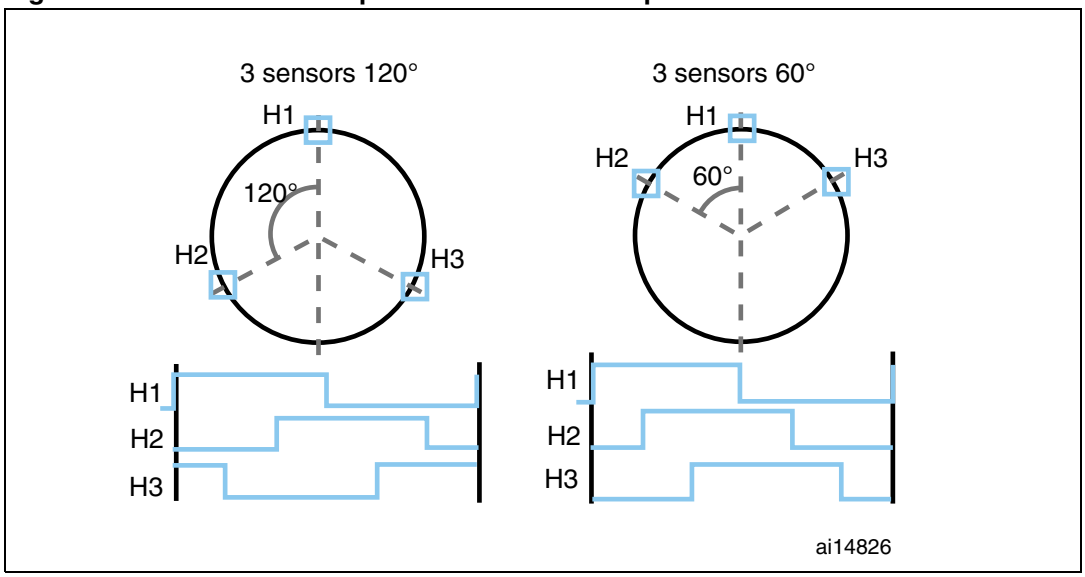
5.2.3 Setting up the system when using Hall-effect sensors

Hall-effect sensors are devices capable of sensing the polarity of the rotor's magnetic field; they provide a logic output, which is 0 or 1 depending on the magnetic pole they face and thus, on the rotor position.

Typically, in a three-phase PM motor, three Hall-effect sensors are used to feed back the rotor position information. They are usually mechanically displaced by either 120° or 60° and the presented firmware library was designed to support both possibilities.

As shown in *Figure 48*, the typical waveforms can be visualized at the sensor outputs in case of 60° and 120° displaced Hall sensors. More particularly, *Figure 48* refers to an electrical period (that is, one mechanical revolution in the case of one pole pair motor).

Figure 48. 60° and 120° displaced Hall sensor output waveforms



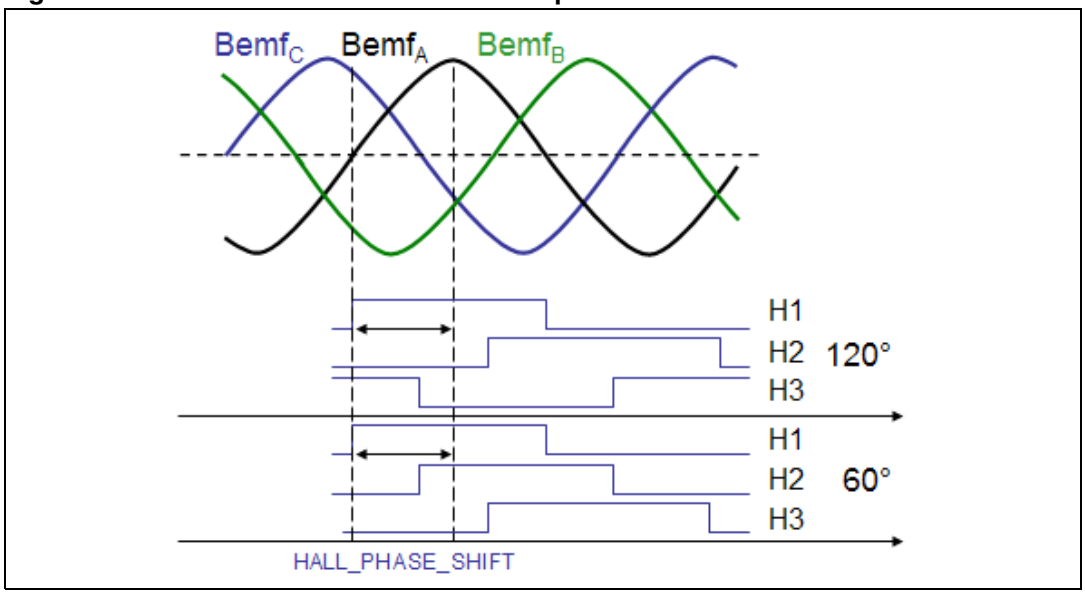
Because the rotor position information they provide is absolute, there is no need for any initial rotor prepositioning. Particular attention must be paid, however, when connecting the sensors to the proper microcontroller inputs.

This software library assumes that the positive rolling direction is the rolling direction of a machine that is fed with a three-phase system of positive sequence. In this case, to work correctly, the software library expects the Hall sensor signal transitions to be in the sequence shown in *Figure 48* for both 60° and 120° displaced Hall sensors.

For these reasons, it is suggested to follow the instructions given below when connecting a Hall-sensor equipped PM motor to your board:

1. Turn the rotor by hand in the direction assumed to be positive and look at the B-emf induced on the three motor phases. For this purpose if the real neutral point is not available, it can be reconstructed by means of three resistors for instance.
2. Connect the motor phases to the hardware respecting the positive sequence. Let “Phase A”, “Phase B” and “Phase C” be the motor phases driven by TIM1_CH1, TIM1_CH2 and TIM1_CH3, respectively (for example, when using the MB459 board, a positive sequence of the motor phases could be connected to J5 2,1 and 3).
3. Turn the rotor by hand in the direction assumed to be positive, look at the three Hall sensor outputs (H1, H2 and H3) and connect them to the selected timer on channels 1, 2 and 3, respectively, making sure that the sequence shown in *Figure 48* is respected.
4. Measure the delay in electrical degrees between the maximum of the B-emf induced on Phase A and the first rising edge of signal H1. Enter it in the MC_hall_param.h header file (HALL_PHASE_SHIFT). For your convenience, an example with HALL_PHASE_SHIFT equal to –90 °C is illustrated in *Figure 49*.

Figure 49. Determination of Hall electrical phase shift



5.3 Encoder sensor feedback processing

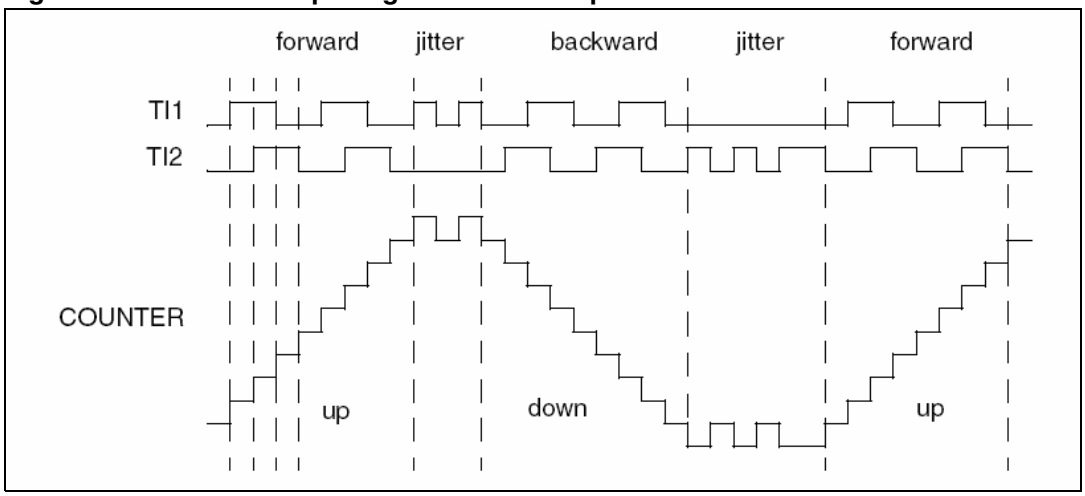
Quadrature incremental encoders are widely used to read the rotor position of electric machines.

As the name implies, incremental encoders actually read angular displacements with respect to an initial position: if that position is known, then the rotor absolute angle is known too. For this reason it is always necessary, when processing the encoder feedback, to perform a rotor prepositioning before the first startup after any fault event or microcontroller reset.

Quadrature encoders have two output signals (represented in *Figure 50* as TI1 and TI2). With these, and with the Root part number 1/F100xx standard timer in encoder interface mode, once the said alignment procedure has been executed, it is possible to get information about the actual rotor angle - and therefore rolling direction - by simply reading the counter of the timer used to decode encoder signals.

For the purpose of MC Library and as information provided by the MC API, rotor angle is expressed in s16degrees (see *Section 7.4: Measurement units*).

Figure 50. Encoder output signals: counter operation



In addition, the rotor angular velocity can be easily calculated as a time derivative of the angular position.

5.3.1 Setting up the system when using an encoder

Extra care should be taken over what is considered to be the positive rolling direction: this software library assumes that the positive rolling direction is the rolling direction of a machine that is fed with a three-phase system of positive sequence.

Because of this, and because of how the encoder output signals are wired to the microcontroller input pins, it is possible to have a sign discrepancy between the real rolling direction and the direction that is read. To avoid this kind of reading error, apply the following procedure:

1. Turn the rotor by hand in the direction assumed to be positive and look at the B-emf induced on the three motor phases. For this purpose, a neutral point may need to be reconstructed with three resistors if the real one is not available.
2. Connect the motor phases to the hardware respecting the positive sequence (for instance when using the MB459 board, a positive sequence of the motor phases may be connected to J5 2,1 and 3).
3. Run the firmware in encoder configuration and turn by hand the rotor in the direction assumed to be positive. If the measured speed shown on the LCD is positive, the connection is correct, otherwise, it can be corrected by simply swapping and rewiring the encoder output signals.

   If this is not practical, a software setting may be modified instead using the ST MC Workbench GUI (see GUI help file).

Alignment settings

Quadrature encoder is a relative position sensor. Considering that absolute information is required for performing field oriented control, it is necessary to somehow establish a 0° position. This task is performed by means of an alignment phase (*Section 8.2.3: Configuration and debug page*, callout 9 in *Figure 64: Configuration and debug page*), and shall be carried out at first motor startup and optionally after any fault event. It consists of imposing a stator flux with a linearly increasing magnitude and a constant orientation.

If properly configured, at the end of this phase, the rotor is locked in a well-known position and the encoder timer counter is initialized accordingly.

6 Working environment

The working environment for the Motor Control SDK is composed of:

- PC
- A third-party integrated development environment (IDE)
- A third-party C-compiler
- JTAG/SWD interface for debugging and programming
- Application board with an STM32F103xx/STM32F100xx properly designed to drive its power stage (PWM outputs to gate driver, ADC channels to read currents, DC bus voltage). Many evaluation boards are available from ST, some of them have an ST-link programmer onboard.
- Three-phase PMSM motor

Table 11 explains the MC SDK file structure for both Web and confidential distributions.

Table 11. File structure

File	Subfile	Description
MC library		Source file of the MC library layer
	interface	Public definitions (interfaces) of classes
	inc (available only in confidential distribution)	Private definitions (data structure) of classes
	src (available only in confidential distribution)	Source files
	obj (available only in confidential distribution)	Compiled classes
	common	Public definitions (interfaces) of classes and definitions exported up to the highest level (PI, Digital Output, reference frame transformation)
MC Application		Source file of the MC application layer
	interface	Public definitions (interfaces) of classes
	inc	Private definitions (data structure) of classes
	src	Source files
UI library		Source file of the User Interface layer
	interface	Public definitions (interfaces) of classes
	inc	Private definitions (data structure) of classes
	src	Source files
	STMFC	LCD graphics library
Libraries		
	FreeRTOS source	FreeRTOS V1.6 distribution (GNU GPL license, http://freertos.org/a00114.html)
	CMSIS	Cortex™ Microcontroller Software Interface Standard v1.30

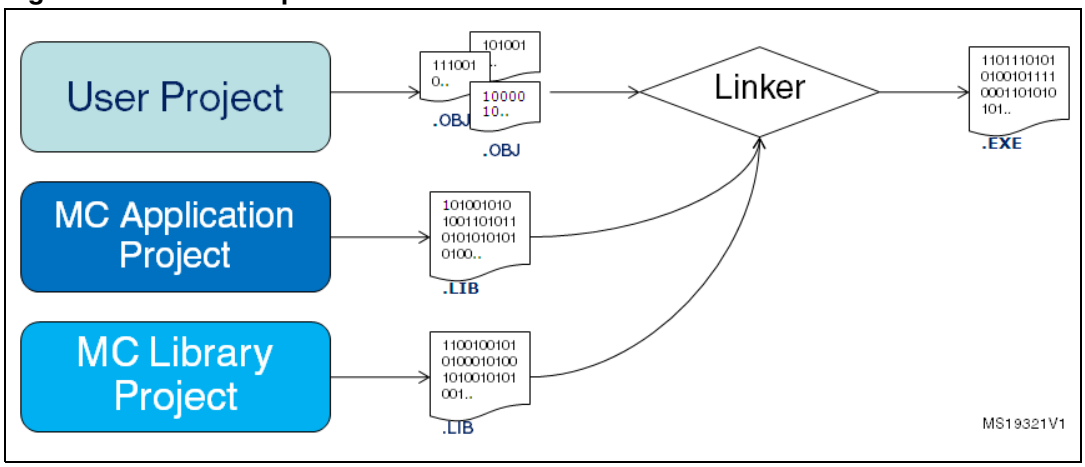
Table 11. File structure (continued)

File	Subfile	Description
	STMF10x_StdPeriph_Driver	STMF10x Standard Peripherals Library Drivers V3.3.0
System &Drive Params		Contains default parameter files (unpacked at installation time, referring to the STM32 MC Kit) or those generated by the ST MC workbench GUI according to user's system
Utilities		Contains code needed for specific functions of ST evaluation boards (LCD drivers, I/O pin assignment, port expanders) and the ST Flash loader demonstrator V2.2.0.
Project		Contains source files of the demonstration user layer application and configuration files for IDEs. In addition, inside each IDE folder (in \MC library Compiled\exe), compiled MC library is provided (in case of web distribution) or created/modified by the IDE (in case of confidential distribution) for single and dual motor drive.
FreeRTOS Project		Contains source files of the demonstration user layer application based on FreeRTOS and configuration files for IDEs. In addition, inside each IDE folder (in \MC library Compiled\exe), compiled MC library is provided (in case of web distribution) or created/modified by the IDE (in case of confidential distribution) for single and dual motor drive.
LCD project		Contains source files of the optional LCD user interface and configuration files for IDEs

6.1 Motor control workspace

The Motor Control SDK is composed of three projects (as shown in *Figure 51*), which constitute the MC workspace.

Figure 51. MC workspace structure



The Motor Control Library project: the collection of all the classes (37 among base and derivative classes) developed to implement all the features. Each class has its own public interface. A public interface is the list of the parameters needed to identify an 'object' of that kind and of the methods (or functions) available. Note that, in the case of a derivative class, applicable methods are those of the specific derived plus those of the base class. Further detail is provided in the *Advanced developers guide for STM32F103xx/STM32F100xx PMSM single/dual FOC library* (UM1053).

All these interfaces constitute the Motor Control Library Interface. The Motor Control Library project is independent from system parameters (the only exception is single/dual drive configuration), and is built as a compiled library, not as an executable file (see *Section 6.3*).

The Motor Control Application project: the application that uses the Motor Control Library layer. Parameters and configurations related to user's application are used here to create right objects and rights, in what is called the run-time system 'boot'.

The Motor Control API is the set of commands granted to the upper layer. This project is built as a compiled library, not as an executable file (see *Section 6.4*).

The user project: the demonstration program included in the SDK that makes use of the Motor Control Application through its MC API and provides it the required clockings and access to Interrupt Handlers. The program can run some useful functionalities (depending on user options), such as serial communication, LCD/keys interface, system variables displaying through DAC.

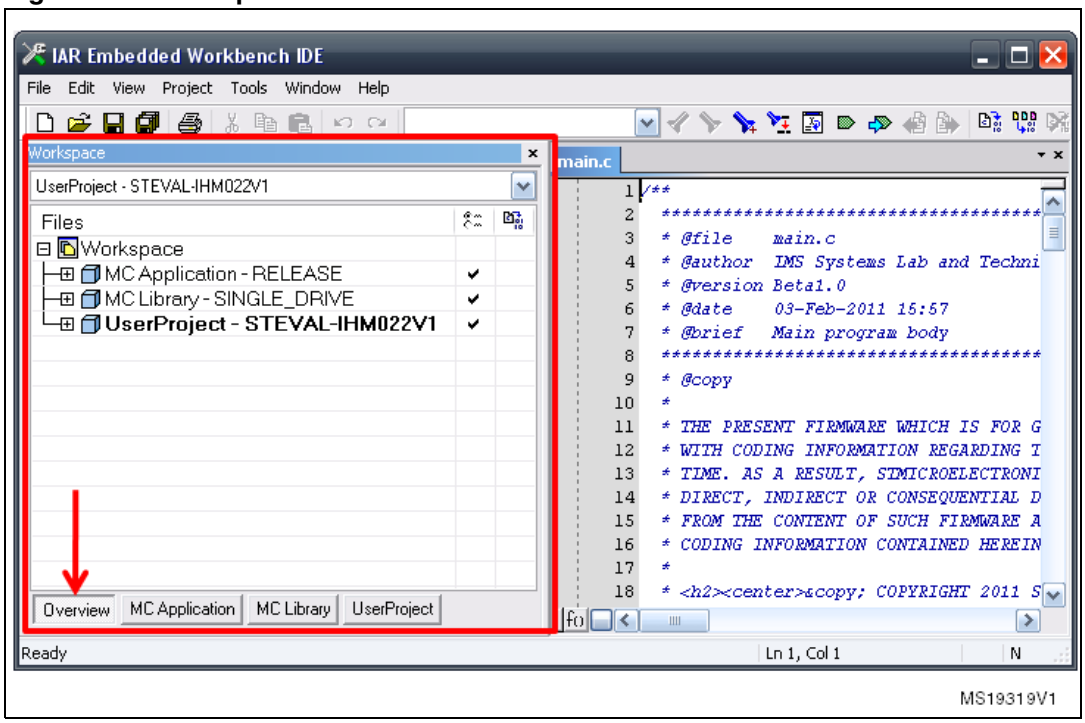
Two equivalent and alternative user projects exist. They differ in how they generate the clocks: one implements a simple time base itself; the other exploits an Operating System, FreeRTOS, to do it.

See *Section 7.3: How to create a user project that interacts with the MC API* to understand how to create a brand new user project.

Previously, built .lib files are linked with the user project in order to generate the file that can be downloaded into microcontroller memory for execution (see *Section 6.5*).

Figure 52 provides an overview of the IAR EWARM IDE workspace (located in Installation folder `\Project\EWARM\Workspace.eww`) configured for dual FOC drive. The following sections provide details on this. The equivalent workspace based on FreeRTOS is located in Installation folder `\FreeRTOS Project\EWARM\RTOS_Workspace.eww`.

Figure 52. Workspace overview



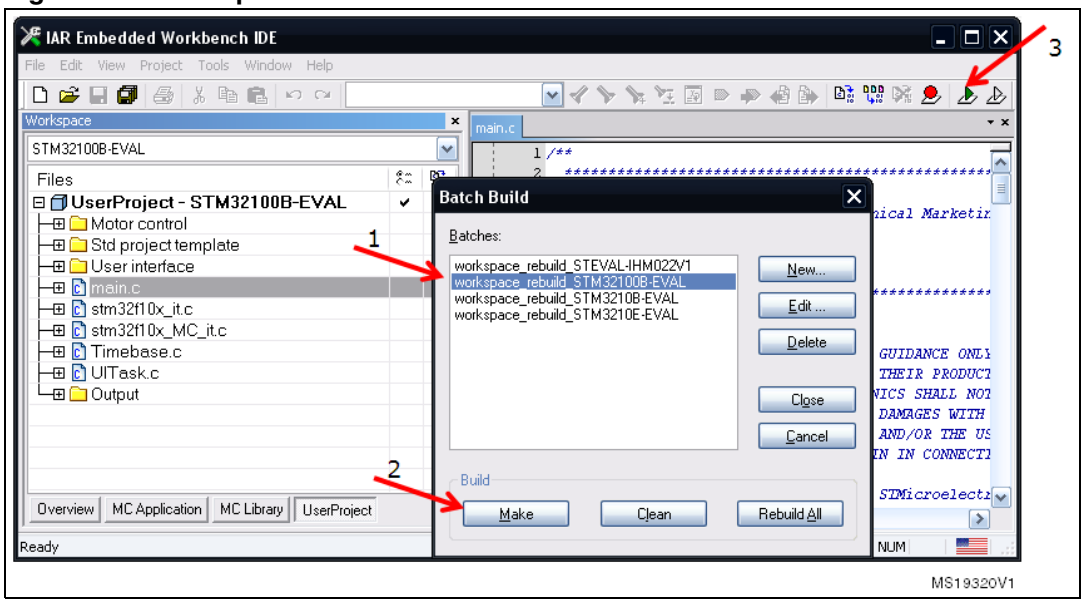
Section 6.2: MC SDK customization process provides the procedure for customizing the Motor Control SDK.

6.2 MC SDK customization process

This section explains how to customize the Motor Control SDK using IAR EWARM IDE so that it corresponds with the user's current system.

1. Using the ST MC Workbench GUI, enter the page information to reflect the system configuration and parameters. This part of the process ends by generating the .h parameters in the correct directory (`Installation folder\System & Drive Params`).
2. If the system is configured to enable the LCD User Interface, download the specific firmware. See *Section 6.6: LCD UI project*.
3. Open the MC workspace of choice:
   - FreeRTOS based: Installation folder\FreeRTOS `Project\EWARM\RTOS_Workspace.eww`
   - Non-FreeRTOS: `Installation folder\Project\EWARM\Workspace.eww`
4. Enable the user project (callout 1 in *Figure 56: User project*) and select the appropriate option from the combo-box (callout 2 in *Figure 56: User project*). If none of the boards displayed is in use, read *Section 6.5: User project* to perform a correct configuration.
5. Press F8 to batch-build the entire workspace. The dialog box shown in *Figure 53: Workspace batch build* appears.
6. Select a batch command (callout 1, *Figure 53*) as for step 4, then click the Make button to make the build (callout 2, *Figure 53*). If no error or relevant warning appears, download the firmware (callout 3, *Figure 53*) and do a test run.

Figure 53. Workspace batch build



It should be noted here that when system configuration or parameters are modified it may be necessary to rebuild all three projects or just one. The batch command conveniently builds all three, to avoid problems. This method is not time-consuming, from the compiler point of view, because if a project is not affected by the modification it is not recompiled.

Then, usually after having run tests on the motor or found a fine tune, the procedure required to change drive parameters, re-build and flash the firmware again is shorter: only steps 1,5,6 need to be done. It's thus suggested that ST MC Workbench GUI and IDE are left open.

The following sections provide more information about each of the three projects of the MC workspace.

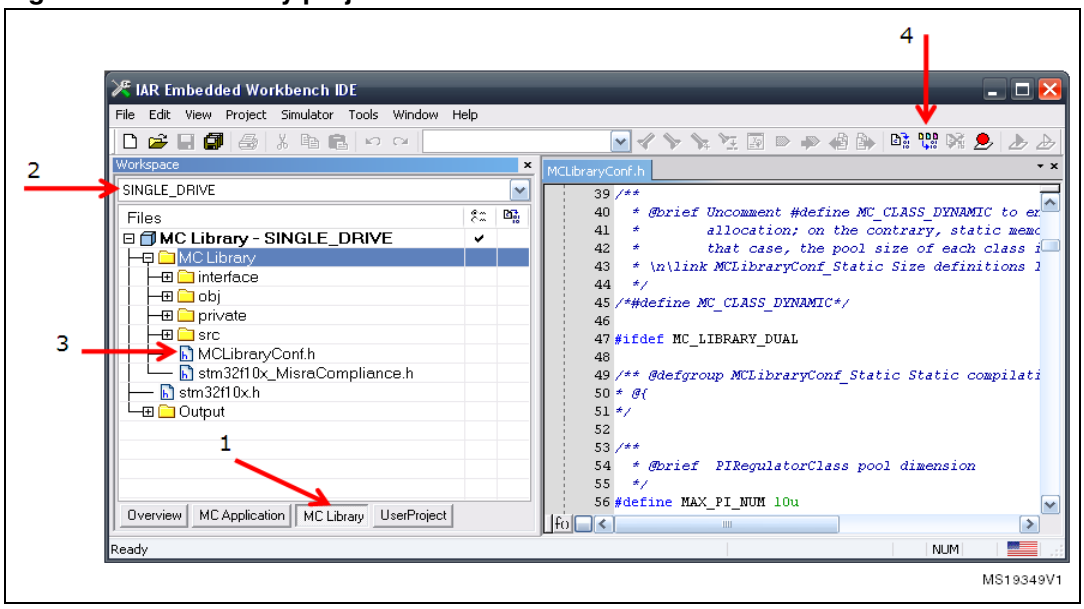
6.3 Motor control library project (confidential distribution)

The MC Library project (available only in confidential distribution) is a collection of classes related to motor control functionalities.

1. To access the project using IAR IDE, open the MC workspace of choice (FreeRTOS based or not) and click the name in the workspace tabbed browser (callout1, *Figure 54*). Remember that IDE toolbars and commands always refer to the active project (the one whose tab is engraved).

   Figure 54 displays the logical arrangement of files on the left-hand side (similar arrangement is in folders). For each class, the MC Library subfolder src contains the source code, private contains its private definitions, interface contains its public interface, obj contains compiled object files of certain classes.

Figure 54. MC Library project



2. Depending on system characteristics, configure the project for single motor drive or dual motor drive by selecting SINGLE_DRIVE or DUAL_DRIVE from the combo-box (callout 2, *Figure 54*).
3. Classes of the MC Library can create new objects resorting to dynamic memory allocation, or statically allotting them from predefined size-pools. This is a matter of preference. Modifying the header file MCLibraryConf.h to choose the allocation (callout 3, *Figure 54*). To activate dynamic allocation, uncomment line 45 (#define MC_CLASS_DYNAMIC). To activate static allocation, comment this line.
4. Once all these settings have been configured and checked, build the library (callout 4, *Figure 54*).

   If SINGLE_DRIVE was selected, the output file MC_Library_single_drive.a is created in `Installation folder \Project\EWARM\MC Library Compiled\Exe` or `Installation folder \FreeRTOS Project\EWARM\MC Library Compiled\Exe`

   If DUAL_DRIVE was selected, the output file MC_Library_dual_drive.a is created in `Installation folder'\Project\EWARM\MC Library Compiled\Exe` or `Installation folder \FreeRTOS Project \EWARM\MC Library Compiled\Exe`.
5. Compliancy with MISRA-C rules 2004 can be checked using IAR EWARM. The test is performed by uncommenting line 35 (#define MISRA_C_2004_BUILD) in the header file Installation folder `\MC Library\Interface\Common\MC_type.h`. The compiler should be configured in Strict ISO/ANSI standard C mode (MISRA C 2004 rule 1.1).

6.4 Motor control application project

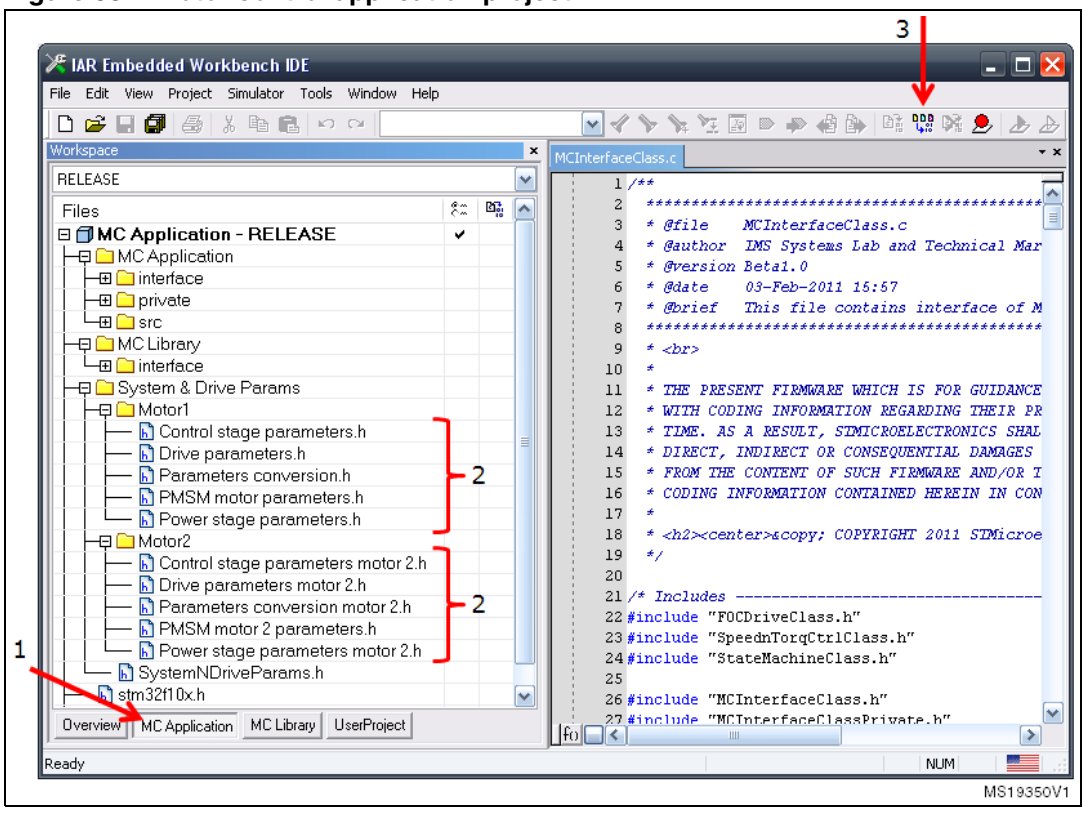
As explained in previous sections, the Motor Control Application project is the Motor Control application program.

1. Access the project using IAR IDE by opening the MC workspace of choice (FreeRTOS based or not), and clicking its name in the workspace tabbed browser (callout 1,

Figure 55). IDE toolbars and commands always refer to the active project (the one whose tab is engraved).

Figure 55 displays the logical arrangement of files, (similar arrangement is in folders).

Figure 55. Motor control application project



Project source files are arranged in the logical folder MC Application.

The MC Library Interface folder contains all the interfaces of each class belonging to the MC Library.

The System and Drive Parameters folder contains the header files that should be filled in so as to describe characteristics and parameters of user's system.

2. To adjust system and drive parameters (callout 2, *Figure 55*), separately for Motor 1 and Motor 2, edit the header files manually or generate them using the ST MC Workbench GUI. The header file SystemNDriveParams.h arranges all these parameters in the form of constant structures for object initialization, so that the MC Application can create the controls required during the initial run-time boot.
3. After these settings have been performed, build the Motor Control Interface (callout 3, *Figure 55*). The output file, MC Interface.a, is created in `Installation folder\Project\EWARM\MC Interface Compiled\Exe` or `Installation folder\FreeRTOS Project \EWARM\MC Interface Compiled\Exe`.

6.5 User project

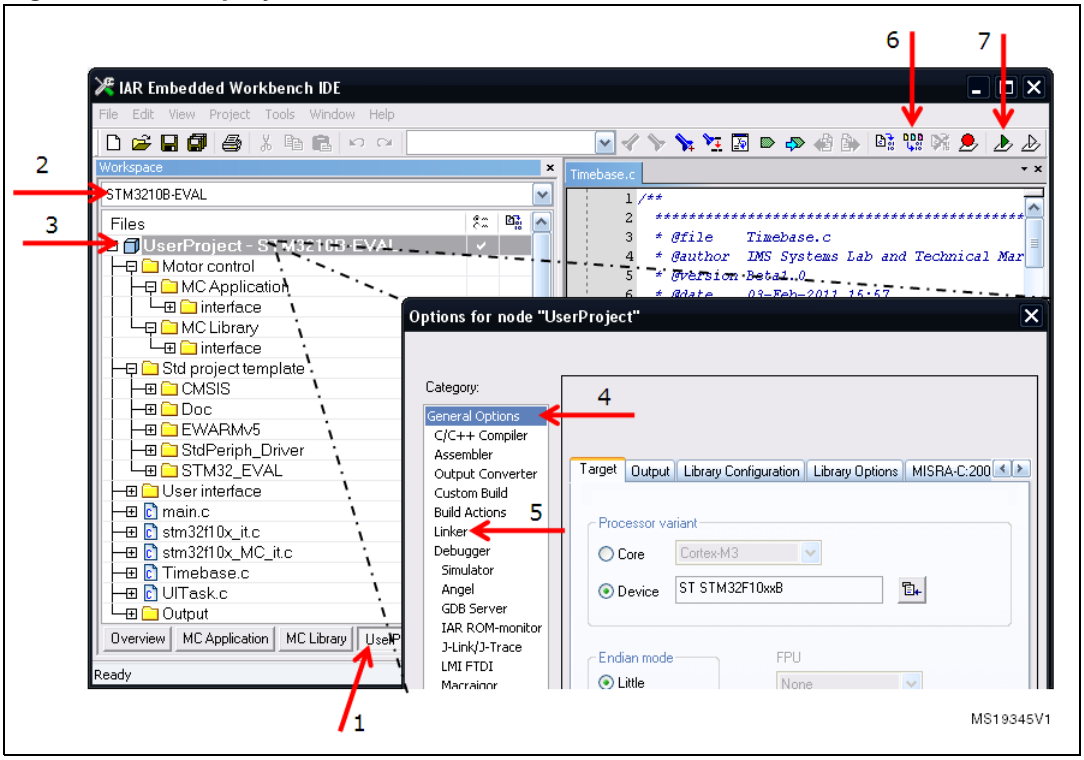
The User project is the application layer that exploits the MC API.

1. Access the project using IAR IDE by opening the MC workspace of choice (FreeRTOS based or not), and clicking its name in the workspace tabbed browser (callout 1,

Figure 56). Remember that IDE toolbars and commands always refer to the active project (the one whose tab is engraved).

Figure 56 displays the logical arrangement of files and actions necessary to set up and download the User project.

Figure 56. User project



The Motor Control folder contains the MC API and interfaces of classes that may also be useful in the user's application (such as PI, Digital Output, reference frame transformation).

The Std project template folder contains:

- STM32F10x Standard Peripherals Library
- CMSIS library, startup and vector table files for EWARMv5 toolchain
- IC drivers (LCD, IOE, SD card) used in STM32 evaluation boards.

All these files belong to V3.3.0 distribution of the STM32 Standard Peripheral Library package (updates available from STMicroelectronics Web site, www.st.com).

This demonstration user project exploits the features offered by the User Interface Library (see *Section 9: User Interface class overview* for further details).

Four project configurations (callout 2, *Figure 56: User project*) are provided, one for each STM32 evaluation board that has been tested with the MC SDK:

- STM32F10B-EVAL
- STM32F10E-EVAL
- STM32F100B-EVAL
- STEVAL-IHM022V1

If the target is one of these boards, just select its name from the combo box. Otherwise the LCD UI should be disabled (using the ST MC Workbench GUI) and the choice is to be done according to *Table 12*:

Table 12. Project configurations

STM32 device part, single/dual drive selection	Viable configuration among existing
STM32F103 low density/medium density	STM32F10B-EVAL
STM32F103 high density/XL density, Single motor drive	STM32F10E-EVAL
STM32F103 high density/XL density, Dual motor drive	STEVAL-IHM022V1
STM32F100 low / medium / high density	STM32F100B-EVAL

Furthermore, if the target is not one of the above mentioned ST evaluation boards, or if you want to modify the configurations provided, right click on **User Project** (callout 3, *Figure 56*) > **Option** to open the **Options** dialog box. Select the correct device part number (callout 4, *Figure 56*) and edit the linker file (callout 5, *Figure 56*).

Note: MC SDK default linker files reserve an amount of flash and RAM (heap) for LCD UI manager (see Section 6.5). We recommend that you restore their total size (please refer to the STM32 datasheet) if you do not need it.

Once all these settings have been performed, the MC Library and MC Application projects are built and you can build the user project (callout 6, *Figure 56*), and download it to the microcontroller memory (callout 7, *Figure 56*).

6.6 LCD UI project

When an STM32 evaluation board equipped with LCD (such as STM3210B-EVAL, STM3210E-EVAL, STM32100B-EVAL, STEVAL-IHM022V1) is in use, you can enable the LCD plus Joystick User Interface—a useful feature of the demonstration user project that can be used as run-time command launcher, fine-tuning or monitoring tool (screens and functionalities are described in depth at *Section 8*). This option can be selected via a setting in the ST MC Workbench GUI. See *Section 6.2*).

In this case, the LCD UI software (single or dual drive configuration) is downloaded in the microcontroller in a reserved area, located at the end of addressable flash memory. Unless you erase it or change the configuration from single-drive to dual-drive or vice-versa, there is no need to download it again. Even disabling the option with the GUI does not mean you need to flash it again when you reenable the option.

The latest STM3210B-MCKIT Motor Control starter kits come with Motor Control Library V3.0 and LCD UI software (single-drive) pre-flashed. If your Motor Control kit has a previous version of Motor Control Library, you do not have the Motor Control kit but you are using one of the mentioned evaluation boards, or you are changing configuration (single-dual), you should follow one of the two procedures explained below to download the LCD UI.

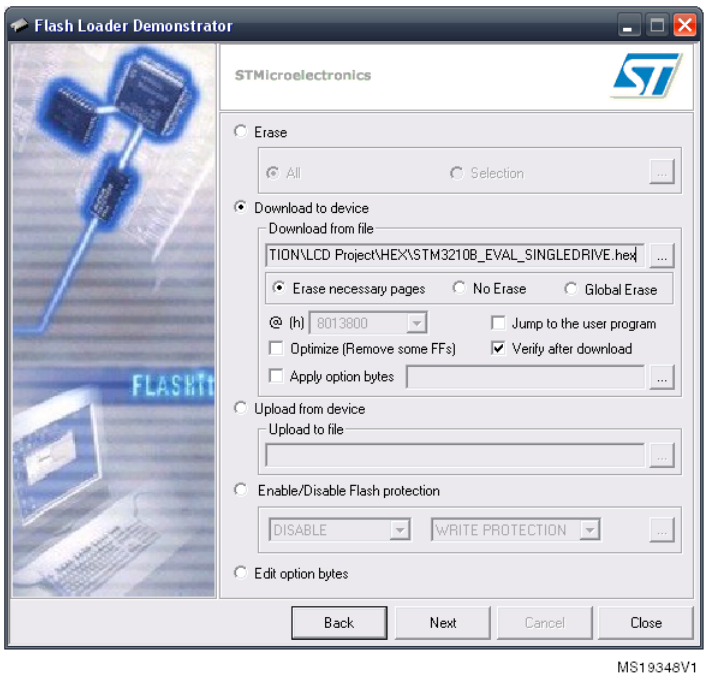
Option 1

This option is straightforward and the preferred one.

1. Use the STM32 and STM8 Flash loader demonstrator PC software package. This is available from the ST web site (http://www.st.com/internet/com/SOFTWARE_RESOURCES/SW_COMPONENT/SW_DEMO/um0462.zip) and in the \Installation folder\Utilities\Flash loader\.)

   The User Manual, UM0462 (included in the package), fully explains how to operate it. For communication purposes, you need to verify that you have an available COM port (RS232) on your PC.
2. After the program is installed, run the Flash loader demonstrator application from the Programs menu, making sure that the device is connected to your PC and that the boot configuration pins are set correctly to boot from the system memory (check the evaluation board user manual).
3. Reset the microcontroller to restart the system memory boot loader code.
4. When the connection is established, the wizard displays the available device information such as the target ID, the firmware version, the supported device, the memory map and the memory protection status. Select the target name in the target combo-box.
5. Click the **Download to device** radio button (see *Figure 57*) and browse to select the appropriate hexadecimal file (STM3210B_EVAL_SINGLEDRIVE.hex, STM32100B_EVAL_SINGLEDRIVE.hex, STM3210E_EVAL_SINGLEDRIVE.hex, STEVAL_IHM022V1_SINGLEDRIVE.hex, STEVAL_IHM022V1_DUALDRIVE.hex) from Installation folder\LCD Project\Hex\.
6. Program the downloading to Flash memory. After the code is successfully flashed, setup the board to reboot from the user Flash memory and reset the microcontroller.
7. To test that the LCD UI is flashed correctly, for both option 1 and 2, open, build and download the user project (see *Section 6.2: MC SDK customization process* and *Section 6.5: User project*).
8. From the debug session, run the firmware (**F5**) and then, after a while, stop debugging (CTRL+Shift+D). The LCD UI is not flashed properly if the program is stalled in a trap inside UITask.c, line 133.

Figure 57. Flash loader wizard screen



Option 2

This option is intended for users who want to modify the LCD UI code.

1. Use an IDE to rebuild and download the LCD UI.
2. After parameter files are generated by the GUI (to set the single/dual drive configuration) using IAR EWARM IDE V5.50, open the workspace located in `Installation folder\LCD Project\EWARM\UI Project.eww`.

Figure 58. LCD UI project

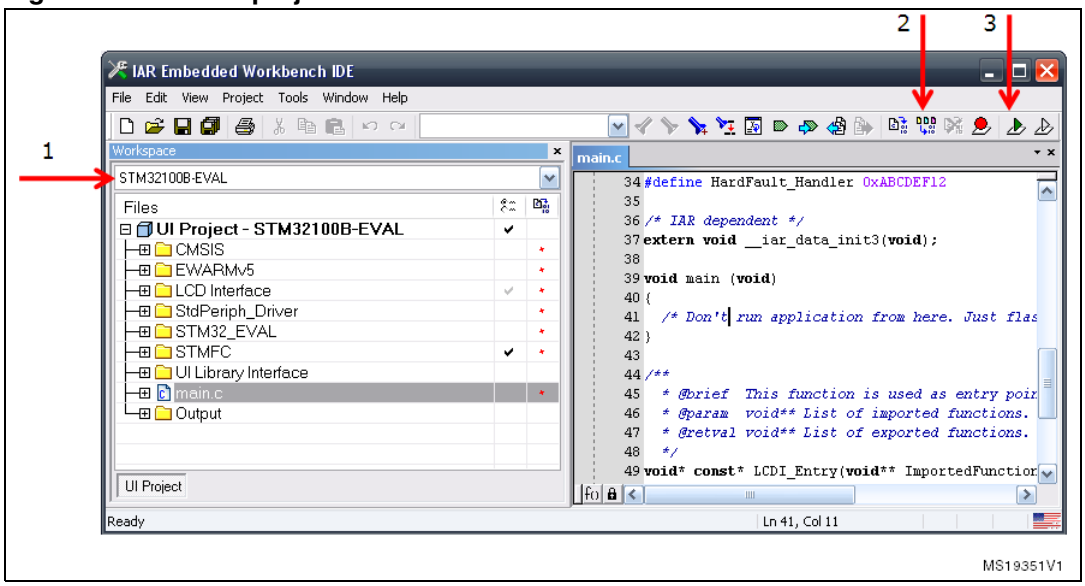


Figure 58 displays the logical arrangement of files (left-hand side) and actions that may be needed for set up and download.

Four project configurations are provided (callout 1, *Figure 58*), one for each STM32 evaluation board that has been tested with the MC SDK:

- STM32F10B-EVAL
- STM32F10E-EVAL
- STM32F100B-EVAL
- STEVAL-IHM022V1

This configuration affects LCD driver and linker file selection.

3. Build the project (callout 2, *Figure 58*), and download it to the microcontroller memory (callout 3, *Figure 58*).
4. To test that the LCD UI is flashed correctly, for both option 1 and 2, open, build and download the user project (see *Section 6.2: MC SDK customization process* and *Section 6.5: User project*).
5. From the debug session, run the firmware (**F5**) and then, after a while, stop debugging (CTRL+Shift+D). The LCD UI is not flashed properly if the program is stalled in a trap in UITask.c, line 133.

7 MC application programming interface (API)

The Motor Control Application is built on top of the Motor Control Library.

On the condition that:

- parameter files are generated by the ST MC workbench GUI, or manually edited starting from default, for the purpose of describing the system configuration
- a user project, such as the one included in the SDK, or any other one that complies with the guidelines described in *Section 7.3: How to create a user project that interacts with the MC API*, is in place.

The MCA grants the user layer the execution of a set of commands, named the MC Application Programming Interface (MC API).

The MC API is divided into two sections and is included in two files: MCInterfaceClass.h and MCTuningClass.h. MCInterfaceClass (details in *Section 7.1*) holds the principal high-level commands, while MCTuningClass (details in *Section 7.2*) acts as a gateway to set and read data to and from objects (such as sensors, PI controllers) belonging to the Motor Control Application.

A third section belongs to MC API, MCtask.h: it holds the MCboot function and tasks (low/medium/high frequency and safety) to be clocked by the user project (see *Section 7.3: How to create a user project that interacts with the MC API* for details)

When the user project calls function MCboot (oMCI, oMCT), the Motor Control Application starts its operations: the booting process begins, objects are created from the Motor Control Library according to system configuration (specified in parameter files), and the application is up and represented by two objects, oMCI and oMCT, whose type is respectively CMCI and CMCT (type definition can be obtained by including MCInterfaceClass.h and MCTuningClass.h). Methods of MCInterfaceClass must be addressed to the oMCI object, oMCT addresses methods of MCTuningClass. oMCI and oMCT are two arrays, each of two elements, so that oMCI[0] and oMCT[0] refers to Motor 1, oMCI[1] and oMCT[1] refer to Motor2.

Function GetMCIList, to be called if necessary after MCboot, returns a pointer to the CMCI oMCI vector instantiated by MCboot. The vector has a length equal to the number of motor drives.

Function GetMCTList, to be called if necessary after MCboot, returns a pointer to the CMCT oMCT vector instantiated by MCboot. The vector has a length equal to the number of motor drives.

7.1 MCInterfaceClass

Commands of the MCInterfaceClass can be grouped in two different typologies:

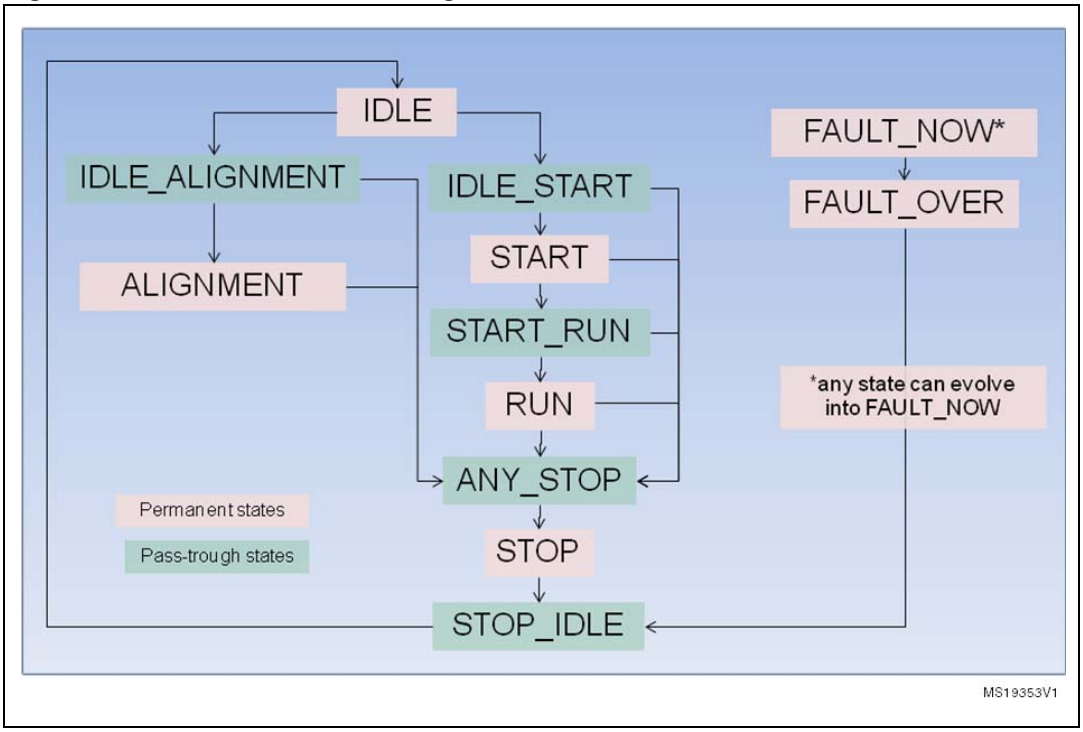
- User commands: commands that become active as soon as they are called. If the state machine is not in the expected state, the command is discarded and the method returns FALSE. The user must manage this by resending the command until it is accepted, or discarding the command.
- Buffered commands: commands that do not execute instantaneously, but are stored in a buffer and become active when the state machine is in a specified state. These commands are not discarded until they become active, unless other delayed commands are sent to the buffer, thus clearing the previous one.

Detailed information can be found in the Motor Control Application source documentation (doxygen compiled .html Help file).

7.1.1 User commands

- `bool MCI_StartMotor(CMCI oMCI)`: starts the motor. It is mandatory to set the target control mode (speed control/torque control) and initial reference before executing this command, otherwise the behavior in run state is unpredictable. Use one of these commands to do this: MCI_ExecSpeedRamp, MCI_ExecTorqueRamp or MCI_SetCurrentReferences.
- `bool MCI_StopMotor(CMCI oMCI)`: stops the motor driving and it disables PWM outputs.
- `bool MCI_FaultAcknowledged(CMCI oMCI)`: this function must be called after a system fault to tell the Motor Control Interface that the user has acknowledged the occurred fault. When a malfunction (overcurrent, overvoltage) is detected by the application, the motor is stopped and the internal state machine goes to the Fault state (see *Figure 59*). The API is locked (it no longer receives commands). The API is unlocked and the state machine returns to Idle when the user sends this MCI_FaultAcknowledged.
- `bool MCI_EncoderAlign(CMCI oMCI)`: this function is only used when an encoder speed sensor is used. It must be called after any system reset and before the first motor start.
- `State_t MCI_GetSTMState(CMCI oMCI)`: returns the state machine status (see *Figure 59*). Further detail is provided in the *Advanced developers guide for STM32F103xx/STM32F100xx PMSM single/dual FOC library* (UM1053).

Figure 59. State machine flow diagram



- `int16_t MCI_GetMecSpeedRef01Hz(CMCI oMCI)`: returns the current mechanical rotor speed reference expressed in tenths of Hertz.
- `int16_t MCI_GetAvrgMecSpeed01Hz(CMCI oMCI)`: returns the last computed average mechanical speed expressed in tenth of Hertz.
- `int16_t MCI_GetTorqueRef(CMCI oMCI)`: returns the present motor torque reference. This value represents the I_q current reference expressed in 's16A'. To convert a current expressed in 's16A' to current expressed in Ampere, use the formula:

  ```
  Current[A] = [Current(s16A) * Vdd micro(V)] / [65536 *
  Rshunt(Ohm) * AmplificationNetworkGain]
  ```

- `int16_t MCI_GetTorque(CMCI oMCI)`: returns the present motor measured torque. This value represents the I_q current expressed in 's16A'. To convert a current expressed in 's16A' to current expressed in Ampere, use the formula:

  ```
  Current[A] = [Current(s16A) * Vdd micro(V)] / [65536 *
  Rshunt(Ohm) * AmplificationNetworkGain]
  ```

- `Curr_Components MCI_GetCurrentsReference(CMCI oMCI)`: returns stator current references I_q and Id in 's16A'. To convert a current expressed in 's16A' to current expressed in Ampere, use the formula:

  ```
  Current[A] = [Current(s16A) * Vdd micro(V)] / [65536 *
  Rshunt(Ohm) * AmplificationNetworkGain].
  ```

- `int16_t MCI_GetPhaseCurrentAmplitude(CMCI oMCI)`: returns the motor phase current amplitude (0-to-peak) in 's16A'. To convert a current expressed in 's16A' to current expressed in Ampere, use the formula:

  ```
  Current[A] = [Current(s16A) * Vdd micro(V)] / [65536 *
  Rshunt(Ohm) * AmplificationNetworkGain].
  ```

- `int16_t MCI_GetPhaseVoltageAmplitude(CMCI oMCI)`: returns the applied motor phase voltage amplitude (0-to-peak) in 's16V'. To convert a voltage expressed in

's16V' to voltage expressed in Volt, use the formula:

```
PhaseVoltage(V) = [PhaseVoltage(s16V) * Vbus(V)] /[sqrt(3)
*32767].
```

- `STC_Modality_t MCI_GetControlMode(CMCI oMCI)`: returns the present control mode: speed mode or torque mode.
- `int16_t MCI_GetImposedMotorDirection(CMCI oMCI)`: returns the motor direction imposed by the last command (MCI_ExecSpeedRamp, MCI_ExecTorqueRamp or MCI_SetCurrentReferences).

7.1.2 Buffered commands

- `void MCI_ExecSpeedRamp(CMCI oMCI, int16_t hFinalSpeed, uint16_t hDurationms)`: sets the control mode in speed control, generates a ramp of speed references from real speed to hFinalSpeed parameter (to be expressed as mechanical rotor speed, tenth of hertz). The ramp execution duration is hDurationms parameter (to be expressed in milliseconds). If hDurationms is set to 0, a step variation is generated. This command is only executed when the state machine is in the START_RUN or RUN state. The user can check the status of the command calling the MCI_IsCommandAcknowledged method.
- `void MCI_ExecTorqueRamp(CMCI oMCI, int16_t hFinalTorque, uint16_t hDurationms)`: sets the control mode in "torque control", generates a ramp of torque references from real torque to hFinalTorque parameter (to be expressed as s16A). The ramp execution duration is hDurationms parameter (to be expressed in milliseconds). If hDurationms is set to 0, a step variation is generated. This command is only executed when the state machine is in the **START_RUN** or **RUN** state. The user can check the status of the command calling the MCI_IsCommandAcknowledged method.
- `void MCI_SetCurrentReferences(CMCI oMCI, Curr_Components Iqdref)`: sets the control mode in "torque control external" (see *Advanced developers guide for STM32F103xx/STM32F100xx PMSM single/dual FOC library* (UM1053)) and directly sets the motor current references I_q and I_d (to be expressed as s16A). This command is only executed when the state machine status is **START_RUN** or **RUN**.
- `CommandState_t MCI_IsCommandAcknowledged(CMCI oMCI)`: returns information about the state of the last buffered command. CommandState_t can be one of the following codes:
  - `MCI_BUFFER_EMPTY` if no buffered command has been called.
  - `MCI_COMMAND_NOT_ALREADY_EXECUTED` if the buffered command condition hasn't already occurred.
  - `MCI_COMMAND_EXECUTED_SUCCESFULLY` if the buffered command has been executed successfully. In this case calling this function reset the command state to `MCI_BUFFER_EMPTY`.
  - `MCI_COMMAND_EXECUTED_UNSUCCESFULLY` if the buffered command has been executed unsuccessfully. In this case calling this function reset the command state to `MCI_BUFFER_EMPTY`.

7.2 MCTuningClass

The MCTuningClass allows the user to obtain objects of the Motor Control Application and apply methods on them.

MCTuningClass.h is divided into three sections:

- Public definitions of all the MC classes exported
- MCT_GetXXX functions, used to receive objects
- For each of the classes exported, a list of applicable methods

For example, if you want to read or set parameters of the speed PI controller:

1. Make sure that the Motor Control Application is already booted, and objects oMCI and oMCT are available (you can receive them through functions GetMCIList or GetMCTList)
2. Declare a 'PIspeed' automatic variable of the type CPI (PI class, type definition at line 85)
3. Obtain the speed PI object (which is actually a pointer) by calling the function MCT_GetSpeedLoopPID (prototype at line 203)
4. Set the KP gain by calling the function PI_SetKP (prototype at line 659).

   The resulting C code could be something like:

```
#include "MCTuningClass.h"
{
...
CPI PIspeedMotor2;
...
PIspeedMotor2 = MCT_GetSpeedLoopPID(oMCT[1]);
PI_SetKP(PIspeedMotor2, NewKpGain);
...
}
```

Note: To reduce flash and RAM occupation, you can disable the MCTuning section of the MC application. This is done by commenting #define MC_TUNING_INTERFACE in the source file MCTask.c, line 80. If you do this, disable the LCD UI and Serial Communication UI too.

7.3 How to create a user project that interacts with the MC API

This section explains how to integrate the Motor Control Application with a user project (thus replacing the provided demonstrative one) in order to take advantage of its API.

1. A timebase is needed to clock the MC Application: the demonstration timebase.c can be considered as an example or used as it is. It uses the Systick timer and its Systick_Handler and PendSV_Handler as resources.

   Alternatively, an Operating System can be used for this purpose, as is done in the FreeRTOS-based demonstration project.

   The timebase should provide the clocks listed in *Table 13*:

Table 13. Integrating the MC Interface in a user project

Number	Function to call	Periodicity	Priority	Preemptiveness
*1	`TSK_LowFrequencyTask`	10 ms	Base	Yes, over non MC functions.
*2	`TSK_MediumFrequencyTask`	Equal to that set in ST MC Workbench, speed regulation rate	Higher than *1	Yes, over *1
*3	`TSK_SafetyTask`	0.5 ms	Higher than *2	Yes, over *1, (optional over *2)

2. include source files:

Note: In the following code, $ stands for Installation Folder.

```
$\Libraries\CMSIS\CM3\CoreSupport\core_cm3.c
$\Libraries\CMSIS\CM3\DeviceSupport\ST\STM32F10x\system_stm32f10x.c
$\Libraries\CMSIS\CM3\DeviceSupport\ST\STM32F10x\startup\XXX\startup_stm32f10x_YYY.s (XXX according to IDE)(YYY according to device)
$\Project\stm32f10x_it.c (removing conditional compilation, can be modified) $\Project\System & Drive Params\stm32f10x_MC_it.c (GUI generated according to system parameters)
```

$\Libraries\STM32F10x_StdPeriph_Driver\src\ (standard peripheral driver sources as needed)

3. include paths:

Note: In the following code, $ stands for Installation Folder.

```
$\Libraries\CMSIS\CM3\CoreSupport\
$\Libraries\CMSIS\CM3\DeviceSupport\ST\STM32F10x\
$\Libraries\STM32F10x_StdPeriph_Driver\inc\
$\MC library\interface\common\
$\MC Application\interface\
$\System & Drive Params\
$\Project\
```

4. include libraries:

```
(if in single motor drive) *\MC Library
Compiled\Exe\MC_Library_single_drive.a
(if in dual motor drive) *\MC Library
Compiled\Exe\MC_Library_dual_drive.a
**\MC Application Compiled\Exe\MC Application.a

* is the path where the MC Library IDE project is located
** is the path where MC Application IDE project is located
```

5. define symbols:

```
USE_STDPERIPH_DRIVER
STM32F10X_MD \ STM32F10X_HD \ STM32F10X_MD_VL \ (according to
STM32 part)
```

6. Set the STM32 NVIC (Nested Vectored Interrupt Controller) priority group configuration (the default option is NVIC_PriorityGroup_3). The alternative option, left to user choice, is NVIC_PriorityGroup_2:

```
NVIC_PriorityGroupConfig(NVIC_PriorityGroup_3);
```

Table 14 shows preemption priorities used by the MC application, user priorities should be lower (higher number):

Table 14. MC application preemption priorities

IRQ	Preemption priority
TIM1 UPDATE	0
TIM8 UPDATE (F103HD/XL only)	0
DMA	0
ADC1_2 (F103 only)	1
ADC3 (F103HD/XL only)	1
ADC1 (F100 only)	1
USART (UI library)	2
TIMx GLOBAL (speed sensor decoding)	2
Timbase	>2

Table 15. Priority configuration, overall (non FreeRTOS)

Component	Preemption priority
MC Library	0,1,2
Timebase (MCA clocks)	3,4
User	5,6,7

Table 16. Priority configuration, overall (FreeRTOS)

Component	Preemption priority	
MC Library	0,1,2 (3 reserved)	
User (only FreeRTOS API)	4,5,6	
FreeRTOS	7	RTOS priority
	MCA clock tasks	Highest
	User tasks	Lower

7. Include the Motor Control Interface in the source files where the API is to be accessed:

```
#include "MCTuningClass.h"
#include "MCInterfaceClass.h"
#include "MCTasks.h"
```

8. Declare a static array of type CMCI (MC Interface class):

```
CMCI oMCI[MC_NUM]; /* MC_NUM is the number of motors to drive*/
```

9. Declare a static array of type CMCT (MC Tuning class):

```
CMCT oMCT[MC_NUM]; /* MC_NUM is the number of motors to drive*/
```

10. Start the MC Interface boot process:

```
MCboot(oMCI,oMCT);
```

11. Send the command to the MC API. For example:

```
MCI_ExecSpeedRamp(oMCI[1],100,1000);
MCI_StartMotor(oMCI[1]);
... /* after a laps of time*/
MCI_StopMotor(oMCI[1]);
```

7.4 Measurement units

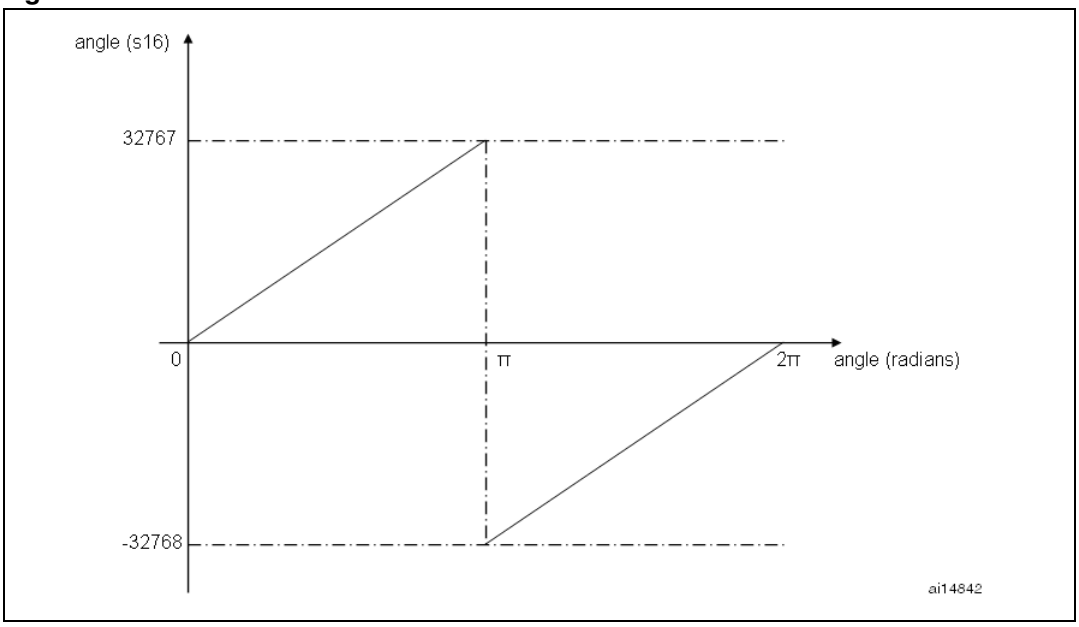
7.4.1 Rotor angle

The rotor angle measurement unit used in the MC API has been named 's16degrees', being

$$1\text{s16degree} = \frac{2\pi}{65536}$$

The picture below shows how an angle expressed in radians can be mapped into the s16degrees domain.

Figure 60. Radians vs s16



7.4.2 Rotor speed

The rotor speed units used in the MC API are:

- Tenth of Hertz (01Hz): straightforwardly, it is:
  $1\ 01Hz = 0.1\ Hz$
- digit per control period (dpp): the dpp format expresses the angular speed as the variation of the electrical angle (expressed in s16 format) within a FOC period, so

$$1dpp = \frac{1s16degree}{1FOCperiod}$$

An angular speed, expressed as frequency in Tenth of Hertz (01Hz), can be easily converted to dpp using the formula:

$$\omega_{dpp} = \omega_{01Hz} \bullet \frac{65536}{10 \bullet FOCfreq_{Hz}}$$

7.4.3 Current measurement

Phase currents measurement unit used in the MC API has been named 's16A', being:

$$1s16A = \frac{MaxMeasureableCurrent_A}{32767}$$

A current, expressed in Ampere, can be easily converted to s16A, using the formula:

$$i_{s16A} = \frac{i_A \times 65536 \bullet RShunt_\Omega \times AmplificationGain}{\mu C\_VDD_V}$$

7.4.4 Voltage measurement

Applied phase voltage unit used in the MC API has been named 's16V', being:

$$1s16V = \frac{MaxApplicablePhaseVoltage_V}{32767}$$

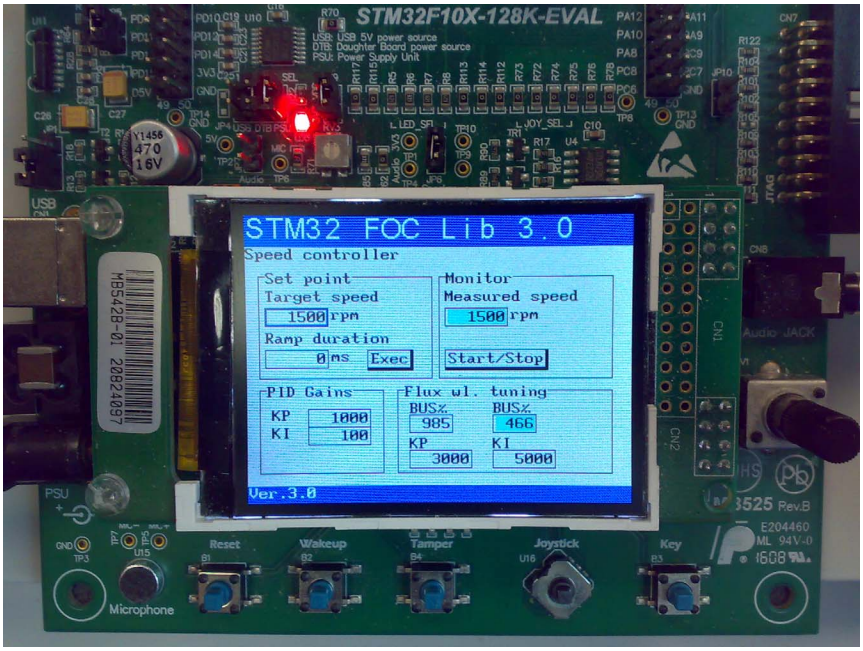
8 LCD user interface

8.1 Running the motor control firmware using the LCD interface

The STM32 motor control library (V3.0) includes a demonstration program that enables you to display drive variables, customize the application by changing parameters, and enable and disable options in real time.

The user interface reference is the one present in the STM32 evaluation boards and is shown in *Figure 61*.

Figure 61. User interface reference



The interface is composed of:

- A 320x240 pixel color LCD screen
- A joystick (see *Table 17* for the list of joystick actions and conventions)
- A push button (KEY button)

Table 17. Joystick actions and conventions

Keyword	User action
UP	Joystick pressed up
DOWN	Joystick pressed down
LEFT	Joystick pressed to the left
RIGHT	Joystick pressed to the right
JOYSEL	Joystick pushed
KEY	Press the KEY push button

In the default firmware configuration, the LCD management is enabled. It can be disabled using the STM32 MC Workbench or disabling the feature and manually changing the line: `define #define LCD_JOYSTICK_BUTTON_FUNCTIONALITY DISABLE` (line 316) of the Drive parameters.h file.

The LCD management is provided by a separate workspace (UI Project) that should be compiled and programmed before the motor control firmware programming.

8.2 LCD User interface structure

The demonstration program is based on circular navigation pages.

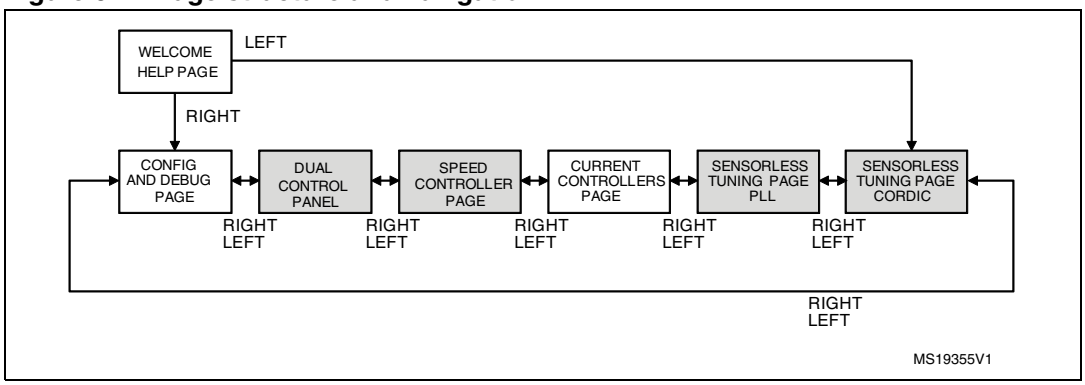
Figure 62 shows the page structure. The visibility of certain pages shown in *Figure 62* depends on the firmware configuration:

- Dual control panel is only present if the firmware is configured for dual motor drive.
- Speed controller page is only present when the firmware is configured in speed mode.
- Sensorless tuning page (PLL) is only present if the firmware is configured with state observer with PLL as primary or auxiliary speed sensor.
- Sensorless tuning page (CORDIC) is only present if the firmware is configured with state observer with CORDIC as primary or auxiliary speed sensor.

To navigate the help menus, use:

- RIGHT: navigate to the next page on the right
- LEFT: navigate to the next page on the left

Figure 62. Page structure and navigation



Each page is composed of a set of controls. *Table 18* presents the list of controls used in the LCD demonstration program.You can navigate between focusable controls in the page by pressing the joystick UP and DOWN. The focused control is highlighted with a blue rectangle. When focused, you can activate the control by pressing JOYSEL.

Table 18. List of controls used in the LCD demonstration program

Control name and Example	Description
Edit box 1500 rpm	Manages a numerical value. It can be "read only" or "read/write". A read only edit box has a gray background and cannot be focusable. A read/write edit box has a white background and can be focusable. When a read/write edit box is focused it can be activated for modification by pressing JOYSEL. An activated read/write edit box has a green background and its value can be modified pressing and/or keep pressed joystick UP/DOWN. When joystick UP is kept pressed, the value is increased with a constant acceleration. When joystick DOWN is kept pressed, the value is decreased with a constant acceleration. The new value is set to the motor control-related object instantaneously when the value changes, unless otherwise mentioned in this manual. The control can be deactivated by pressing JOYSEL again.
Combo-box Speed ▼	Manages a list of predefined values. The values associated to a combo-box are text strings that correspond with different configurations or options of the firmware. For example, Speed or Torque control mode. The combo-box is always focusable and when focused can be activated for modification by pressing JOYSEL. An activated combo-box has a green background and its value can be modified by pressing the joystick UP/DOWN. The combo-box values are circular. Going UP from the first value selects the last value and vice versa. The new value is set to the motor control-related object instantaneously when the value changes, unless otherwise mentioned in this manual. The control can be deactivated by pressing JOYSEL again.
Button Fault ack	Sends commands to motor control-related object. For example, a start/stop button. This button can be enabled or disabled. A disabled button is drawn in light gray and cannot be focusable. An enabled button is painted in black and can be focusable. When focused, a button can be activated by pressing JOYSEL. This corresponds to "pushing" the button and sending the related command.
Check box Link X	Enables or disables an option. It is always focusable and when focused can be activated by pressing JOYSEL. This correspond to "check/uncheck" the control and means "enable/disable" the option.

8.2.1 Motor control application layer configuration (speed sensor)

The motor control application layer can be configured to use a position and speed sensor as a primary or auxiliary speed sensor.

A primary speed and position sensor is used by the FOC algorithm to drive the motor. It is mandatory to configure a primary speed sensor.

An auxiliary speed and position sensor may be used in parallel with the primary sensor for debugging purposes. It is not used by the FOC algorithm. It is not mandatory to configure an auxiliary speed sensor.

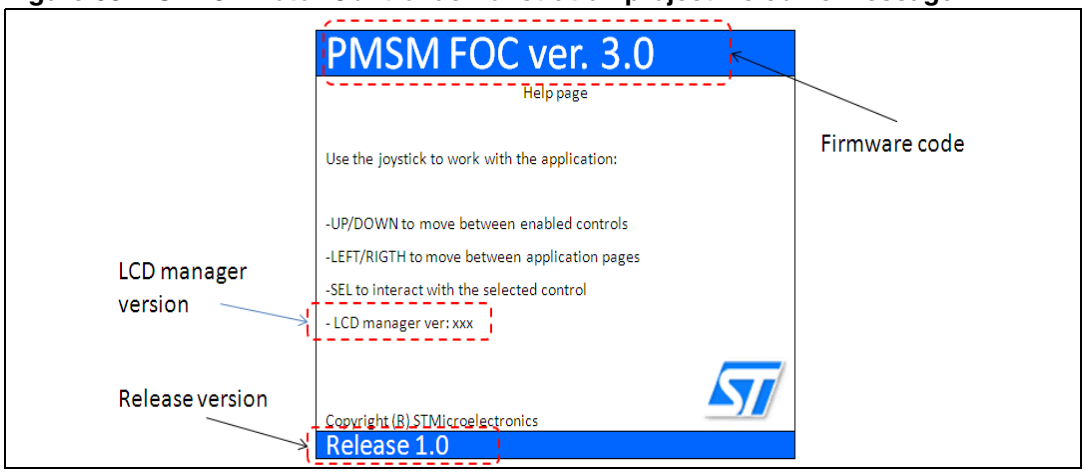
The following sensors are implemented in the MC library:

- Hall sensor
- Quadrature encoder
- State observer plus PLL
- State observer plus CORDIC

8.2.2 Welcome message

After the STM32 evaluation board is powered on or reset, a welcome message displays on the LCD screen to inform the user about the firmware code loaded and the version of the release. See *Figure 63*.

Figure 63. STM32 Motor Control demonstration project welcome message


PMSM FOC ver. 3.0
Help page
Firmware code
Use the joystick to work with the application:
-UP/DOWN to move between enabled controls
-LEFT/RIGTH to move between application pages
-SEL to interact with the selected control
LCD manager version
- LCD manager ver: xxx
Release version
Copyright (B) STMicroelectronics
Release 1.0

The page shows a brief help on the operation of the demonstration program. You can navigate to the next page by pressing the joystick RIGHT, or go back to the previous page by pressing the joystick LEFT.

Pressing the KEY button at any time starts or stops the motor. If you are using a dual motor control, pressing KEY stops both motors.

8.2.3 Configuration and debug page

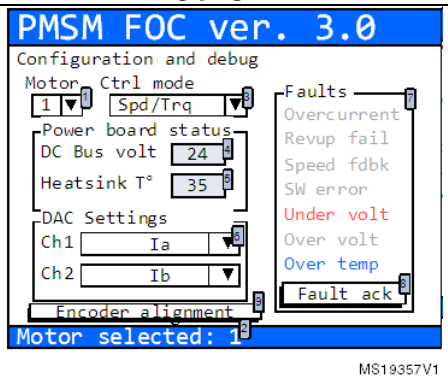
Press the joystick RIGHT from the welcome page to enter the configuration and debug page.

To navigate between focusable controls on the page, press the joystick UP/DOWN.

Use the configuration and debug page shown in *Figure 64* to:

- select the active motor drive (field 1 in *Figure 64*). This control is present only for dual motor control applications. This combo-box enables you to select the active motor drive. Once the active motor is selected it is shown in the status bar present at the bottom of the screen (field 2 in *Figure 64*). Commands performed on, or feedback from a control are only relative to the active motor.
- select the control mode (field 3 in *Figure 64*). Two control modes are available: speed and torque. You can change the control mode from speed to torque and vice versa on-the-fly even if the motor is already running.

Figure 64. Configuration and debug page



- read the DC bus voltage value (field 4 in *Figure 64*). This control is read-only.
- read the heat sink temperature value (field 5 in *Figure 64*). This control is read-only.
- select the variables to be put in output through DAC channels (field 6 in *Figure 64*). These controls are present only if the DAC option is enabled in the firmware. The list of variables also depends on firmware settings. *Table 20* and *Table 21* present the list of variables that can be present in these combo-boxes, depending on the configuration.

  Table 19 shows the conventions used for DAC outputs of Currents, Voltages, Electrical angles, Motor Speed and Observed BEMF.

Note: Table 19 assumes that the DAC voltage range is 0 to 3.3 volt.

Table 19. Definitions

Definition	Description
Currents quantity (Ia, Iq, …)	Current quantities are output to DAC as signed 16-bit numeric quantities converted in the range of DAC voltage range. – Zero current is at 1.65 volt of DAC output. – Maximum positive current (that runs from inverter to the motor) is at 3.3 volt of DAC output. – Maximum negative current (that runs from inverter to the motor) is at 0 volt of DAC output.
Voltage quantity (Valpha, Vq)	Voltage quantities are output to DAC as signed 16-bit numeric quantities converted in the range of DAC voltage range. – 0% of modulation index is at 1.65 volt of DAC output. – 100% of modulation index is at 0 and 3.3 volt of DAC output.
Electrical angle	This is expressed in digits converted to the DAC voltage range. – 180 electrical degrees is at 0 and 3.3 volt of DAC output. – 0 electrical degrees is at 1.65 volt of DAC output.
Motor speed	This is proportional to the maximum application speed. – 0 speed is at 1.65 volt of DAC output. – Maximum positive application speed is at 3.3 volt of DAC output. – Maximum negative application speed is at 0 volt of DAC output.
Observer BEMF voltage	This is referenced to the maximum application speed and the voltage constant configured in the firmware. Values of BEMF present at maximum application speed is at 0 and 3.3 volt of DAC output.

Table 20. List of DAC variables

Variable name	Description
Ia	Measured phase A motor current
Ib	Measured phase B motor current
Ialpha	Measured alpha component of motor phase's current expressed in alpha/beta reference.
Ibeta	Measured beta component of motor phase's current expressed in alpha/beta reference
Iq	Measured "q" component of motor phase's current expressed in q/d reference.
Id	Measured "d" component of motor phase's current expressed in q/d reference
Iq ref	Target "q" component of motor phase's current expressed in q/d reference
Id ref	Target "d" component of motor phase's current expressed in q/d reference
Vq	Forced "q" component of motor phase's voltage expressed in q/d reference
Vd	Forced "d" component of motor phase's voltage expressed in q/d reference
Valpha	Forced alpha component of motor phase's voltage expressed in alpha/beta reference.
Vbeta	Forced beta component of motor phase's voltage expressed in alpha/beta reference
Meas. El Angle	Measured motor electrical angle. This variable is present only if a "real" sensor (encoder, Hall) is configured as primary or auxiliary speed sensor and it is relative to this sensor
Meas. Rotor Speed	Measured motor speed. This variable is present only if a "real" sensor (encoder, Hall) is configured as primary or auxiliary speed sensor and it is relative to this sensor
Obs. El Angle	Observed motor electrical angle. This variable is present only if a "state observer" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor
Obs. Rotor Speed	Observed motor speed. This variable is present only if a "state observer" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor
Obs. Ialpha	Observed alpha component of motor phase's current expressed in alpha/beta reference. This variable is present only if a "state observer" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. Ibeta	Observed beta component of motor phase's current expressed in alpha/beta reference. This variable is present only if a "state observer" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor
Obs. B-emf alpha	Observed alpha component of motor BEMF expressed in alpha/beta reference. This variable is present only if a "state observer" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. B-emf beta	Observed beta component of motor BEMF expressed in alpha/beta reference. This variable is present only if a "state observer" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Exp. B-emf level	The expected Bemf squared level.
Obs. B-emf level	The observed Bemf squared level.

Table 20. List of DAC variables (continued)

Variable name	Description
User 1	User defined DAC variable. *Section 9.9* describes how to configure user defined DAC variables.
User 2	User defined DAC variable. *Section 9.9* describes how to configure user defined DAC variables.

Observed variables (Obs.) in *Table 20* refer to a configuration that uses only one sensorless speed sensor configured as primary or auxiliary sensor and refers to that state observer sensor. When the firmware is configured to use two sensorless speed sensors, state observer plus PLL and state observer plus CORDIC as primary and auxiliary speed sensor, the DAC variables related to each state observer sensor are indicated in *Table 21*.

Table 21. DAC variables related to each state observer sensor when two state observer speed sensors are selected

Variable name	Description
Obs. El Ang. (PLL)	Observed motor electrical angle. This variable is present only if a "state observer plus PLL" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. Ialpha (PLL)	Observed alpha component of motor phase's current expressed in alpha/beta reference. This variable is present only if a "state observer plus PLL" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. Rot. Spd (PLL)	Observed motor speed. This variable is present only if a "state observer plus PLL" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. Ibeta (PLL)	Observed beta component of motor phase's current expressed in alpha/beta reference. This variable is present only if a "state observer plus PLL" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. Bemf a.(PLL)	Observed alpha component of motor BEMF expressed in alpha/beta reference. This variable is present only if a "state observer plus PLL" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. Bemf b.(PLL)	Observed beta component of motor BEMF expressed in alpha/beta reference. This variable is present only if a "state observer plus PLL" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. El Ang. (CR)	Observed motor electrical angle. This variable is present only if a "state observer plus CORDIC" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. Rot. Spd (CR)	Observed motor speed. This variable is present only if a "state observer plus CORDIC" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. Ialpha (CR)	Observed alpha component of motor phase's current expressed in alpha/beta reference. This variable is present only if a "state observer plus CORDIC" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.

Table 21. DAC variables related to each state observer sensor when two state observer speed sensors are selected (continued)

Variable name	Description
Obs. Ibeta (CR)	Observed beta component of motor phase's current expressed in alpha/beta reference. This variable is present only if a "state observer plus CORDIC" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. Bemf a.(CR)	Observed alpha component of motor BEMF expressed in alpha/beta reference. This variable is present only if a "state observer plus CORDIC" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.
Obs. Bemf b.(CR)	Observed beta component of motor BEMF expressed in alpha/beta reference. This variable is present only if a "state observer plus CORDIC" sensor is configured as primary or auxiliary speed sensor and it is relative to this sensor.

Table 21 lists the DAC variables related to each state observer sensor when two state observer speed sensors are selected.

- It is possible to read the list of fault causes (field 7 in *Figure 64*) if fault conditions have occurred, or if they are still present. The list of possible faults is summarized in *Table 22* and is represented by the list of labels in the LCD screen (point 7 in *Figure 63*). If a fault condition occurred and is over, the relative label is displayed in blue. If a fault condition is still present, the relative label is displayed in red. It is gray if there is no error.
- To acknowledge the fault condition, press the "Fault ack" button (field 8 in *Figure 64*). If a fault condition occurs, the motor is stopped and it is no longer possible to navigate in the other pages. In this condition it is not possible to restart the motor until the fault condition is over and the occurred faults have been acknowledged by the user pushing the "Fault ack" button (point 8 in *Figure 63*). If a fault condition is running, the "Fault ack" button is disabled.

Table 22. Fault conditions list

Fault	Description
Overcurrent	This fault occurs when the microcontroller break input signal is activated. It is usually used to indicate hardware over current condition.
Revup fail	This fault occurs when the programmed rev-up sequence ends without validating the speed sensor information. The rev-up sequence is performed only when state observer is configured as primary speed sensor.
Speed fdbk	This fault occurs only in RUN state when the sensor no longer meets the conditions of reliability.
SW error	This fault occurs when software detects a general fault condition. In present implementation the software error is raised when the FOC frequency is too high to be sustainable by the microcontroller.
Under volt	This fault occurs when the DC bus voltage is below the configured threshold.
Over volt	This fault occurs when the DC bus voltage is above the configured threshold. If the dissipative brake resistor management is enabled this fault is not raised.
Over temp	This fault occurs when the heat sink temperature is above the configured threshold.

- Execute encoder initialization. If the firmware is configured to use the encoder as primary speed sensor or auxiliary speed sensor, the "encoder alignment" button is also present. In this case, the alignment of the encoder is required only once after each reset of the microcontroller.

8.2.4 Dual control panel page

This page is present only if the firmware is configured for dual motor drive.

To enter the dual control page, press the joystick RIGHT from configuration and debug page.

It is possible to navigate between focusable controls present in the page pressing joystick UP/DOWN.

The dual control panel page shown *Figure 65* is used to send commands and get feedback from both motors. It is divided into three groups:

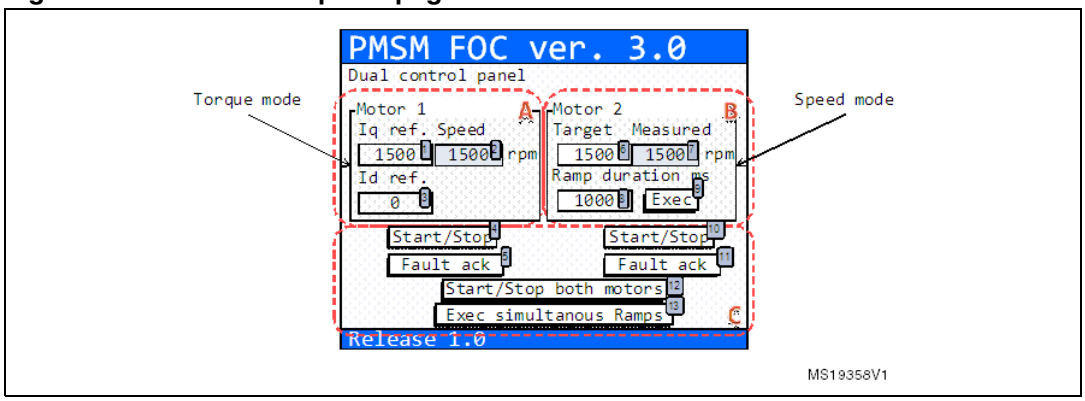
- Groups A and group B depend on speed/torque settings. The group content is updated on-the-fly when the control mode (torque/speed) is changed in the configuration and debug page. The control present in group A is related to the first motor. The control present in group B relates to the second motor.
- Group C does not depend on speed/torque settings. The control present in this group is related to both motors.

Figure 65 shows an example in which the first motor is set in torque mode and the second motor is set in speed mode.

The controls present in this page are used as follows:

- To set the I_q reference (field 1 in *Figure 65*). This is related to motor 1 and is only present if motor 1 is set in torque mode. I_q reference is expressed in s16A. In this page, the current references are always expressed as Cartesian coordinates (I_q,I_d).

Figure 65. Dual control panel page



- To set the I_d reference (field 3 in *Figure 65*). This is related to motor 1. This control is only present if motor 1 is set in torque mode. Id reference is expressed in s16A. In this page the current references are expressed always as Cartesian coordinates (I_q,I_d).

Note: To convert current expressed in Amps to current expressed in digit is possible to use the formula:

*Current(s16A) = [Current(Amp) * 65536 * Rshunt * Aop] / Vdd micro.*

- Set the final motor speed of a speed ramp (field 6 in *Figure 65*). This is related to motor 2. This control is only present if motor 2 is set in speed mode. Motor speed is expressed in RPM. The value set in this control is not automatically sent to the motor

control related object but it is used to perform a speed ramp execution. See the Exec button description (field 9 in *Figure 65*).

- Set the duration of a speed ramp (field 8 in *Figure 65*). This is related to motor 2. This control is only present if motor 2 is set in speed mode. Duration is expressed in milliseconds. The value set in this control is not automatically sent to the motor control related object, but it is used to perform a speed ramp execution. See the Exec button description (field 9 in *Figure 65*). It is possible to set a duration value of 0 to program a ramp with an instantaneous change in the speed reference from the current speed to the final motor speed (field 6 in *Figure 65*).
- Execute a speed ramp by pushing the "Exec" button (field 9 in *Figure 65*). This is related to motor 2. This control is only present if motor 2 is set in speed mode. The Exec speed ramp command is sent to the motor control related object together with the final motor speed and duration currently selected (field 6 and 8 in *Figure 65*). The Exec speed ramp command performs a speed ramp from the current speed to the final motor speed in a time defined by duration. The command is buffered and takes effect only when the motor is in RUN state.
- To read the motor speed (field 2 and 7 in *Figure 65* respectively for motor 1 and motor 2). Motor speed is expressed in RPM. This control is read-only.
- Send a start/stop command (field 4 for motor 1, field 10 for motor 2 in *Figure 65*). This is performed pushing the start/stop button. A start/stop command means: start the motor if it is stopped, or stop the motor if it is running. If the drive is configured in speed mode when the motor starts, a speed ramp with the latest values of final motor speed and duration is performed. If a fault condition occurs at any time, the motor is stopped (if running) and the start/stop button is disabled.
- When a fault condition is over, the "Fault ack" button (*Figure 65* field 5 for motor 1, field 11 for motor 2) is enabled. Pushing this button acknowledges the fault conditions that have occurred. After the fault is acknowledged, the start/stop button becomes available again. When a fault occurs and before it is acknowledged, it is only possible to navigate in the Dual control panel page and the Configuration and debug page.
- To start or stop both motors simultaneously, push the "start/stop both motors" button (field 12 in *Figure 65*). This button is enabled only when the motors are both in Idle state or both in RUN state. If any of the motors are configured in speed mode when they start, a speed ramp with the last values of final motor speed and duration is performed. It is possible to stop both motors at any time by pushing the KEY button.
- To execute simultaneous speed ramps on both motors, push the Exec simultaneous ramps button (field 13 in *Figure 65*). This button is disabled when at least one of the two motors is configured in torque mode. The Exec speed ramp command is sent to both motor control objects together with related final motor speed and duration currently selected. The Exec speed ramp command performs a speed ramp from the current speed to the final motor speed in a time defined by duration for each motor. The commands are buffered and take effect only when the related motor is in RUN state.

8.2.5 Speed controller page

This page is only present if the control mode set in ctrl mode (field 3 in *Figure 64*) is speed mode.

To enter the speed controller page, press the joystick RIGHT from the configuration and debug page (or from dual control panel page, if the firmware is configured in dual motor drive).

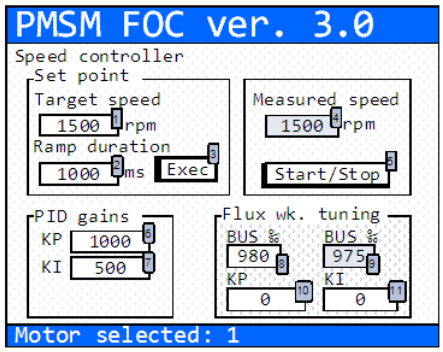
It is possible to navigate between focusable controls present in the page pressing joystick UP/DOWN.

The speed controller page shown in *Figure 66* is used to send commands and get feedback related to speed controller from the active motor. There are four groups of control in this page list in the table below.

Table 23. Control groups

Control group	Description
Set point	Used to configure and execute a speed ramp.
PID gains	Used to change the speed controller gains in real-time.
Flux wk. tuning	Used to tune the flux weakening related variables.
Measured speed with start/stop button	Composed of two controls that are also present in the current controllers page and in the sensorless tuning page, this provides for fast access to the measured speed and to the motor start/stop function.

Figure 66. Speed controllers page



If the firmware is configured as dual motor drive, it is possible to know which is the active motor by reading the label at the bottom of the page. To change the active motor, change the motor field in the configuration and debug page (field 1, *Figure 66*).

Table 24 lists the actions that can be performed using this page.

Table 24. Speed controllers page controls

Control	Description
Target speed (field 1 in *Figure 66*)	This sets the final motor speed of a speed ramp for the active motor. Motor speed is expressed in RPM. The value set in this control is not automatically sent to the motor control related object, but it is used to perform a speed ramp execution. See Exec button description (field 3 in *Figure 66*)
Ramp duration (field 2 in *Figure 66*)	This sets the duration of a speed ramp for the active motor. Duration is expressed in milliseconds. The value set in this control is not automatically sent to motor control related object but it is used to perform a speed ramp execution. See description of "exec" button (field 3 in *Figure 66*). It is possible to set a duration value of 0 to program a ramp with an instantaneous change in the speed reference from the current speed to the final motor speed (field 1 in *Figure 66*).

Table 24. Speed controllers page controls (continued)

Control	Description
Exec button (field 3 in *Figure 66*)	This executes a speed ramp for the active motor. The execute speed ramp command is sent to the motor control related object together with final motor speed and duration presently selected (field 1 and 2 in *Figure 66*). The execute speed ramp command performs a speed ramp from the current speed to the final motor speed in a time defined by duration. The command is buffered and takes effect only when the motor becomes in RUN state.
Measured speed (field 4 in *Figure 66*)	This reads the motor speed for the active motor. Motor speed is expressed in RPM and is a read-only control.
Start/Stop button (field 5 in *Figure 66*)	This sends a start/stop command for the active motor. A start/stop command starts the motor if it is stopped, or stops a running motor. Used with a motor start, a speed ramp with the last values of final motor speed and duration is performed. If a fault condition occurs at any time, the motor is stopped (if running) and the configuration and debug page displays.
Speed PID gain KP (field 6 in *Figure 66*)	This sets the proportional coefficient of the speed controller for the active motor. The value set in this control is automatically sent to motor control related object, allowing the run-time tuning of the speed controller.
Speed PID gain KI (field 7 in *Figure 66*)	This sets the integral coefficient of the speed controller for the active motor. The value set in this control is automatically sent to motor control related object, allowing the run-time tuning of speed controller.
Bus‰ (field 8 in *Figure 66*)	This sets the maximum percentage quantity of DC bus that can be utilized for a flux weakening operation for the active motor. This control is present only if the flux weakening feature is enabled in the firmware. This value should be a trade-off between bus voltage exploitation (higher bus means greater speed can be achieved) and control margin (the remaining bus voltage from that value to 100% is available for current regulation used by current regulators.If it is too low, control is no longer possible). The value set in this control is automatically sent to the motor control related object, allowing the run-time tuning of flux weakening controller. The value is expressed in permillage (‰) of DC bus voltage.
Bus‰ (field 9 in *Figure 66*)	This reads the quantity of DC bus voltage percentage presently used for the active motor and is a read-only control. This control is present only if the flux weakening feature is enabled in the firmware. The value is actually expressed in permillage (‰) of DC bus voltage.
Flux wk PI gain KP (field 10 in *Figure 66*)	the proportional coefficient of the flux weakening controller for the active motor. This control is only present if the flux weakening feature is enabled in the firmware. The value set in this control is automatically sent to the motor control related object, allowing the run-time tuning of flux weakening controller.
Flux wk PI gain KI (field 11 in *Figure 66*)	Sets the integral coefficient of the flux weakening controller for the active motor. This control is only present if the flux weakening feature is enabled in the firmware. The value set in this control is automatically sent to the motor control related object, allowing the run-time tuning of flux weakening controller.

8.2.6 Current controllers page

To enter the current controllers page, press the joystick RIGHT from speed controller page (or from one of the described above pages if speed controller page is not visible).

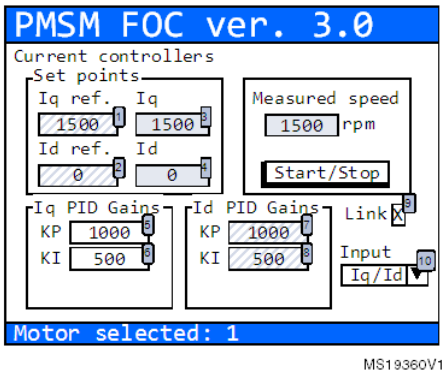
It is possible to navigate between focusable controls present in the page pressing joystick UP/DOWN.

The current controller page shown in *Figure 67* is used to send commands and get feedback related to current controllers, from the active motor. There are five control groups in this page listed in th e table below.

Table 25. Control groups

Control group	Description
Set point	Used to set the current references and read measured currents
Iq PID gains	Used to change in real time the speed controllers gains
Id PID gains	
Measured speed with start/stop button	Composed of two controls that are also present in the current controllers page and in the sensorless tuning page, this provides for fast access to the measured speed and to the motor start/stop function
Option selection	Selects options

Figure 67. Current controllers page



If the firmware is configured as dual motor drive is possible to know which is the active motor reading the label at the bottom of the page. To change the active motor, the motor field in the configuration and debug page has to be changed (*Figure 67* field 1).

Table 26 lists the actions that can be performed using this page.

Table 26. Current controllers page controls

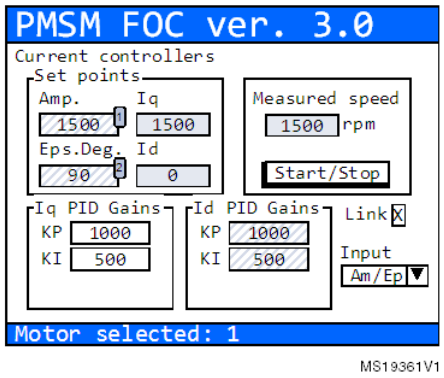
Control	Description
I_q reference (field 1 in *Figure 67*)	To set and read the I_q reference for the active motor. This control is read-only if the active motor is set in speed mode, otherwise it can be modified. The I_q reference is expressed in s16A. To convert current expressed in Amps to current expressed in digits, use the formula: Current(s16A) = [Current(Amp) * 65536 * Rshunt * Aop] / Vdd micro
I_d reference (field 2 in *Figure 67*)	To set and read the I_d reference for the active motor. This control is usually read-only if the active motor is set in speed mode otherwise it can be modified. The I_d reference is expressed in digits. It is also possible to configure the firmware to have Id reference modifiable even in speed mode. To convert current expressed in Amps to current expressed in s16A is possible to use the formula: Current(s16A) = [Current(Amp) * 65536 * Rshunt * Aop] / Vdd micro

Table 26. Current controllers page controls (continued)

Control	Description
Measured I_q (field 3 in *Figure 67*)	To read the measured I_q for the active motor. Measured I_q is expressed in s16A and is a read-only control.
Iq PI(D) gain, KP (field 5 in *Figure 67*)	To set the proportional coefficient of the I_q current controller for the active motor. The value set in this control is automatically sent to the motor control related object, allowing the run-time tuning of current controller.
Iq PI(D) gain, KI (field 6 in *Figure 67*)	To set the integral coefficient of the Iq current controller for the active motor. The value set in this control is automatically sent to the motor control related object, allowing the run-time tuning of current controller.
Id PI(D) gain, KP (field 7 in *Figure 67*)	To set the proportional coefficient of the I_d current controller for the active motor. The value set in this control is automatically sent to the motor control related object, allowing the run-time tuning of current controller. This control is only read if the link check box is checked.
Id PI(D) gain, KI (field 8 in *Figure 67*)	To set the integral coefficient of the I_d current controller for the active motor. The value set in this control is automatically sent to the motor control related object, allowing the run-time tuning of current controller. This control is only read if the link check box is checked.

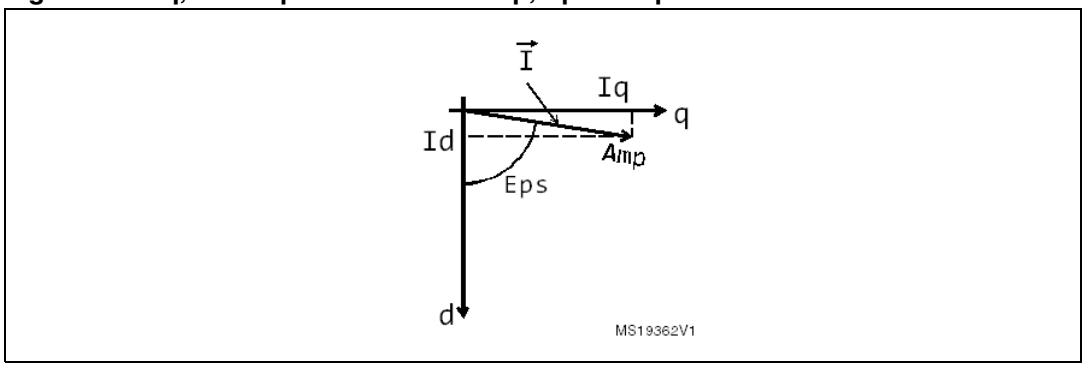
To enable or disable the link between I_q and I_d controllers KP and KI gains. This is performed checking or unchecking the link check box (field 9 in *Figure 67*). It is possible to change the current reference variables from Cartesian coordinates (Iq/Id) to polar coordinates (Amp, Eps *Figure 68*) using the input combo-box (field 10 in *Figure 67*). If polar coordinates are selected, the current controller page is modified as in *Figure 68*.

Figure 68. Current controllers page with polar coordinates



- The Amp field (field 1 in *Figure 68*) is used to set and read the current reference amplitude for the active motor. This control is read-only if the active motor is set in speed mode, otherwise it is modifiable. Amplitude reference is expressed in digits.
- The Eps field (field 2 in *Figure 68*) is used to set and read the current reference phase for the active motor. This control is read-only if active motor is set in speed mode, it otherwise is modifiable. Phase is expressed in degrees.

Figure 69. Iq, Id component versus Amp, Eps component



8.2.7 Sensorless tuning STO & PLL page

This page is present only if the firmware is configured to use a state observer (STO) plus PLL sensor set as a primary or auxiliary speed and position sensor. If the state observer sensor is set as an auxiliary speed and position sensor, the (AUX) label will be shown near the page title (See field 9 in *Figure 70*).

To enter the sensorless tuning page, press the joystick RIGHT from current controllers page.

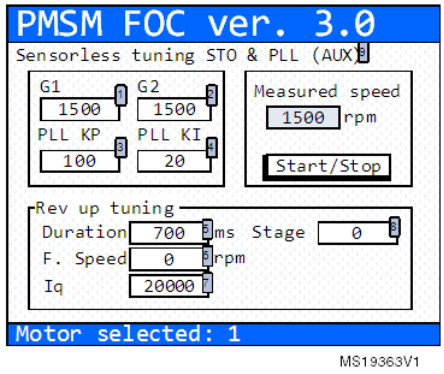
It is possible to navigate between focusable controls present in the page pressing joystick UP/DOWN.

The sensorless tuning page shown in *Figure 70* is used to send commands and get feedback related to state observer plus PLL object from the active motor. There are three groups of control in this page.

Table 27. Control groups

Control group	Description
State observer tuning	Used to configure the parameters of the state observer object in real-time
Rev up tuning gains	Used to change the start up related parameters in real-time. This group is only present if the state observer plus PLL sensor is selected as primary speed and position sensor.
Measured speed with start/stop button	Composed of two controls that are also present in the current controllers page and in the sensorless tuning page, this provides for fast access to the measured speed and to the motor start/stop function

Figure 70. Sensorless tuning STO & PLL page



If the firmware is configured as dual motor drive, it is possible to know which is the active motor by reading the label at the bottom of the page. To change the active motor, change the motor field in the configuration and debug page.

Table 28 lists the actions that can be performed using this page.

Table 28. Sensorless tuning STO & PLL page controls

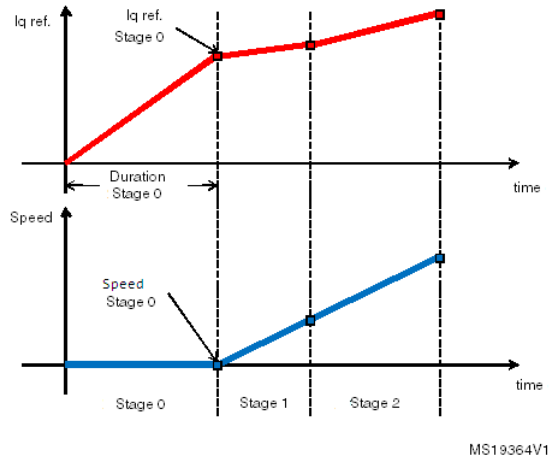
Control	Description
G1 (field 1 in *Figure 70*)	To modify the G1 gain parameter in real-time. The value set in this control is automatically sent to the motor control related object, allowing the run-time tuning of state observer object. This value is proportional to the K1 observer gain and is equal to C2 STO object parameter (See *STM32 FOC PMSM FW library v3_0 developer Help file.chm*).
G2 (field 2 in *Figure 70*)	To modify the G2 gain parameter in real-time. The value set in this control is automatically sent to motor control related object, allowing the run-time tuning of state observer object. This value is proportional to the K2 observer gain and is equal to C4 STO object parameter (See *STM32 FOC PMSM FW library v3_0 developer Help file.chm*).
PLL KP (field 3 in *Figure 70*)	To set the proportional coefficient of the PLL for the active motor. The value set in this control is automatically sent to motor control related object, allowing the run-time tuning of the current controller. This control is only present if the state observer + PLL object is set as the primary or auxiliary speed and position sensor, and if the PLL tuning option is enabled in the firmware.
PLL KI (field 4 in *Figure 70*)	To set the integral coefficient of the PLL for the active motor. The value set in this control is automatically sent to motor control related object, allowing the run-time tuning of current controller. This control is only present if state observer + PLL object is set as the primary or auxiliary speed and position sensor, and if the PLL tuning option is enabled in the firmware.
Duration (field 5 in *Figure 70*)	To set the duration of the active rev-up stage for the active motor. The value set in this control is automatically sent to motor control related object and becomes active on next motor start-up, allowing the tuning of the rev-up sequence. Duration is expressed in milliseconds.
F. Speed (field 6 in *Figure 70*)	To set the final mechanical speed for the active motor and active rev-up controller stage. The value set in this control is automatically sent to motor control related object and becomes active on next motor start-up, allowing the run-time tuning of rev-up sequence. Final mechanical speed is expressed in RPM.

Table 28. Sensorless tuning STO & PLL page controls (continued)

Control	Description
I_q (field 7 in *Figure 70*)	To set the final torque reference for the active motor and active rev-up controller stage. The value set in this control is automatically sent to motor control related object and becomes active on next motor start-up, allowing the tuning of rev-up sequence. Final torque reference is expressed in Id current and becomes active on next motor start-up. To convert current expressed in Amps to current expressed in digits, use the formula: Current(s16A) = [Current(Amp) * 65536 * Rshunt * Aop] / Vdd micro.
Stage (Field 8 in *Figure 70*)	To set the active rev-up stage that receives the Duration, F. Speed and Final torque reference (Iq) new values set in Fields 5, 6 and 7.

The rev-up sequence consists of five stages. *Figure 71* shows an example of rev-up sequence. It is possible to tune each stage in run-time using rows 5-8 of *Table 28*.

Figure 71. Example of rev-up sequence



8.2.8 Sensorless tuning STO & CORDIC page

This page is only present if the firmware is configured to use a state observer plus CORDIC sensor set as a primary or auxiliary speed and position sensor. If the state observer sensor is set as auxiliary speed and position sensor, the (AUX) label will be shown near the page title (See field 7 in *Figure 72*).

To enter the sensorless tuning page, press the joystick RIGHT from current controllers page.

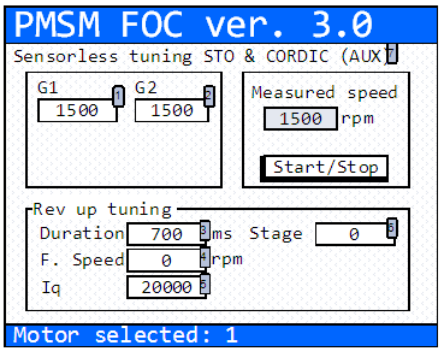
It is possible to navigate between focusable controls present in the page pressing joystick UP/DOWN.

The sensorless tuning page shown in *Figure 72* is used to send commands and get feedbacks, related to state observer plus CORDIC object, from the active motor. There are three groups of controls in this page.

Table 29. Control groups

Control group	Description
State observer tuning	Used to configure the parameters of the state observer object in real-time
Rev up tuning gains	Used to change the start-up related parameters in real-time. This group is only present if the state observer plus CORDIC sensor is selected as primary speed and position sensor.
Measured speed with start/stop button	Composed of two controls that are also present in the current controllers page and in the sensorless tuning page, this provides for fast access to the measured speed and to the motor start/stop function

Figure 72. Sensorless tuning STO & CORDIC page



If the firmware is configured as dual motor drive, it is possible to know which is the active motor by reading the label at the bottom of the page. To change the active motor, change the motor field in the configuration and debug page.

Table 30 lists the actions that can be performed using this page.

Table 30. Sensorless tuning STO & PLL page controls

Control	Description
G1 (field 1 in *Figure 72*)	To modify the G1 gain parameter in real-time. The value set in this control is automatically sent to the motor control related object, allowing the run-time tuning of state observer object. This value is proportional to the K1 observer gain and is equal to C2 STO object parameter (See doxygen.chm).
G2 (field 2 in *Figure 72*)	To modify the G2 gain parameter in real-time. The value set in this control is automatically sent to motor control related object, allowing the run-time tuning of state observer object. This value is proportional to the K2 observer gain and is equal to C4 STO object parameter (See doxygen.chm).
Duration (field 3 in *Figure 72*)	To set the duration of the active rev-up stage for the active motor. The value set in this control is automatically sent to motor control related object and becomes active on next motor start-up, allowing the tuning of the rev-up sequence. Duration is expressed in milliseconds.
F. Speed (field 4 in *Figure 72*)	To set the final mechanical speed for the active motor and active rev-up controller stage. The value set in this control is automatically sent to motor control related object and becomes active on next motor start-up, allowing the run-time tuning of rev-up sequence. Final mechanical speed is expressed in RPM.

Table 30. Sensorless tuning STO & PLL page controls (continued)

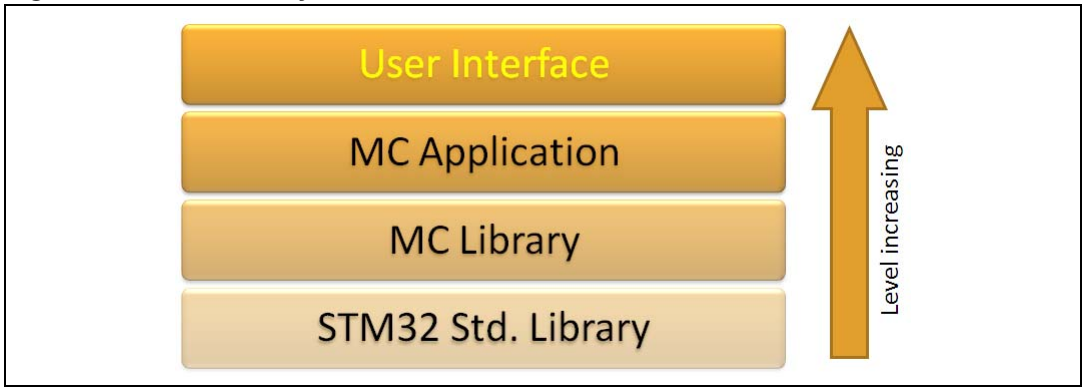
Control	Description
I_q (field 5 in *Figure 72*)	To set the final torque reference for the active motor and active rev-up controller stage. The value set in this control is automatically sent to motor control related object and becomes active on next motor start-up, allowing the tuning of rev-up sequence. Final torque reference is expressed in Id current and becomes active on next motor start-up. To convert current expressed in Amps to current expressed in digits, use the formula: Current(s16A) = [Current(Amp) * 65536 * Rshunt * Aop] / Vdd micro.
Stage (Field 8 in *Figure 70*)	To set the active rev-up stage that receives the Duration, F. Speed and Final torque reference (Iq) new values set in Fields 5, 6 and 7.

It is possible to set the active rev-up stage (field 6 in *Figure 72*). *Figure 71* shows an example of rev-up sequence.

9 User Interface class overview

The STM32 FOC motor control firmware is arranged in software layers (*Figure 73*). Each level can include the interface of the next level, with the exception that the STM32 Std. Library can be included in every level.

Figure 73. Software layers



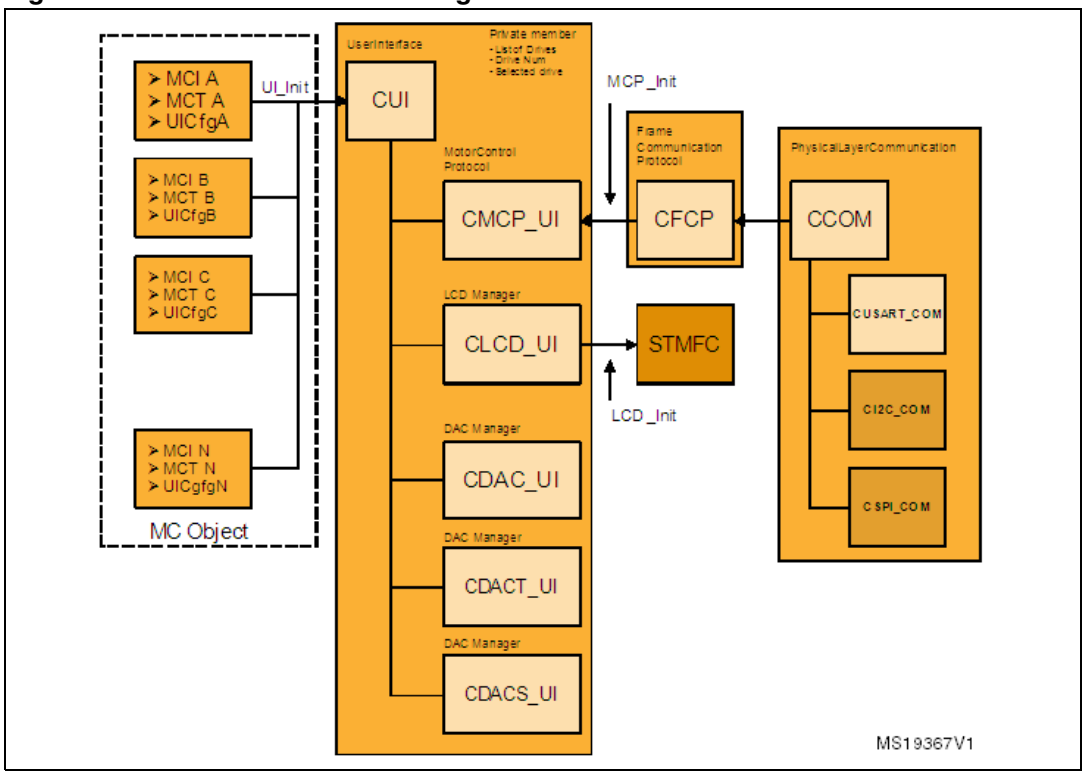
This section describes the details of the User interface layer. This is the highest software level present in the released STM32 PMSM FOC Library v3.0.

The user interface class (CUI) manages the interaction between the user and the motor control library (MC Library) via the motor control application layer (MC Application).

In the current implementation, the user interaction can be performed by any of the following devices: digital to analog converter (DAC), LCD display plus joystick, serial communication. For each of these devices one or more derived class of UI object have been implemented (see *Figure 74*):

- LCD Manager Class (CLCD_UI) is used to interact with the LCD color display. It has been implemented over the LCD graphical library STMFC written in C++ language.
- Motor control protocol (CMCP_UI) is used to manage serial communications. The serial communication is implemented over the Frame communication protocol class CFCP (Transport layer). The CFCP is, in turn, implemented over a physical layer communication class CCOM (Physical layer). Daughter classes of CCOM are CUSART_COM, CI2C_COM and CSPI_COM. Presently only the CUSART_COM, that implements the physical serial communication using USART channel, has been implemented and only with PC master microcontroller slave configuration.
- DAC manager (CDAC_UI) is used to manage the DAC outputs using a real DAC peripheral. This is the default setting when DAC output is enabled using the STM32F100 (Value line) or STM32F103xE (High density) devices.

Figure 74. User interface block diagram



- The DAC manager (CDACT_UI) manages DAC outputs using a virtual DAC implemented with a filtered PWM output generated by a timer peripheral. This is the default setting when DAC output is enabled using the STM32F103xB (Medium density) device.
- CDACS_UI does not perform a digital to analog conversion but sends the output variables through SPI communication.

9.1 User interface class (CUI)

This class implements the interaction between the user and the motor control library (MC Library) using the motor control application layer (MC Application). In particular the CUI object is to be used for reading or writing relevant motor control quantities (for example, Electrical torque, Motor speed) and execute the motor control commands exported by MC Application (for example, Start motor, execute speed or torque ramps, customize the startup). Any object of this class must be linked to a derived class object.

The user interface class requires the following steps (implemented inside the method UI_Init.):

- Defines the number of motor drives managed by user interface objects. Implementation of MC firmware manages at most two motor drives. The CUI can manage N drivers.
- Creates the link between MC tuning (MCT) MC interface (MCI) objects and the user interface objects.

  See *Section 7.1: MCInterfaceClass* and *Section 7.2: MCTuningClass* for more information about MCI and MCT.
- Configures the options of user interface objects. See *Section 9.2: User interface configuration*.

Once initialized the UI object is able to:

- Get and set the selected motor control drive that the UI operates on(UI_GetSlectedMC/UI_SelectMC). For example, UI_SelectMC is required in the case of dual motor control in order to select the active drive to which commands are applied (for example, Set/Get register, start motor).
- Get and set registers (UI_SetReg/UI_GetReg). A register is a relevant MC quantity that can be exported from, or imposed to, MC objects through MCI / MCT. The list of this quantity MC_PROTOCOL_REG_xxx is exported by UserInterfaceClass.h. See *STM32 FOC PMSM FW library v3_0 developer Help file.chm*.

  For example: To set up the proportional term of the speed controller of the second motor:

1. Obtain the oMCT and oMCI object through GetMCIList, GetMCTList functions, exported by MCTasks.h. The oMCI and oMCT are two arrays of objects.

```
CMCI oMCI[MC_NUM];
CMCT oMCT[MC_NUM];
...
GetMCIList(oMCI);
GeMCTList(oMCT);
...
```

2. Instantiate and initialize a CUI object.

```
oUI = UI_NewObject(MC_NULL);
UI_Init(oUI, MC_NUM, oMCI, oMCT, MC_NULL);
```

3. Select the motor drives

```
UI_SelectMC(oUI, 2);
```

4. Set the MC_PROTOCOL_REG_SPEED_KP register value.

```
UI_SetReg(oUI, MC_PROTOCOL_REG_SPEED_KP, <Desired value>);
```

   A similar sequence can be used to get values from MC objects replacing the UI_SetReg method with UI_GetReg method.

- Execute a MC command (UI_ExecCmd). The list of available MC commands MC_PROTOCOL_CMD_xxx is exported by UserInterfaceClass.h. See *STM32 FOC PMSM FW library v3_0 developer Help file.chm*.

  For example: To execute a Start command to the first motor:

1. Obtain the oMCT and oMCI object through GetMCIList, GetMCTList functions, exported by MCTasks.h. The oMCI and oMCT are two arrays of objects.

```
CMCI oMCI[MC_NUM];
CMCT oMCT[MC_NUM];
...
GetMCIList(oMCI);
GeMCTList(oMCT);
...
```

2. Instantiate and initialize a CUI object.

```
oUI = UI_NewObject(MC_NULL);
UI_Init(oUI, MC_NUM, oMCI, oMCT, MC_NULL);
```

3. Select the motor drives

```
UI_SelectMC(oUI, 2);
```

4. Provide a command (for example, Start motor).

```
UI_ExecCmd (oUI, MC_PROTOCOL_CMD_START_MOTOR);
```

- Execute torque and speed ramps, set current reference, and set or get revup data. See STM32 FOC PMSM FW library v3_0 developer Help file.chm.
- Execute specific functions dedicated to CDAC objects. See *Section 9.7: DAC Manager Class (CDACx_UI)*.

Note: All derived classes of CUI act on MCI and MCT objects through the CUI methods. For instance, the LCD manager updates a motor control quantity calling UI_SetReg method and so on.

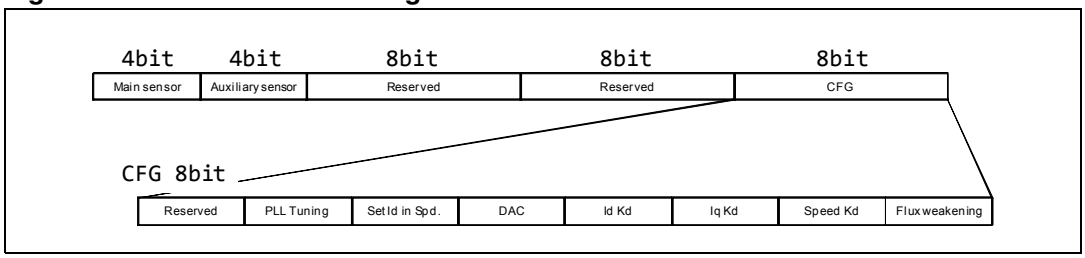
9.2 User interface configuration

User interface object and its derivatives are configured using a 32bit configuration value (see *Figure 75*).

The first byte of this register contains the sensor configuration. Each sensor is defined using 4 bits. The values UI_SCODE_xxx are exported by UserInterfaceClass.h. See *Table 31*.

The first 4-bit defines the main speed and position sensor. The second 4-bit defines the auxiliary speed and position sensor.

Figure 75. User interface configuration bit field



The remaining bit field values UI_CFGOPT_xxx are exported by UserInterfaceClass.h. See *Table 32*.

To configure the user interface object, the configuration should be passed in the UI_Init function as 5th parameter. The 5th parameter of UI_Init function is an array of configuration values, one for each motor drive.

Note: The 32-bit configuration value is automatically computed by preprocessor in the Parameters conversion.h file basing on the configuration present in the System & Drive Params folder. It can be manually edited by the user.

Table 31. User interface configuration - Sensor codes

Code	Description
UI_SCODE_HALL	This code identifies the Hall sensor
UI_SCODE_ENC	This code identifies the Encoder sensor
UI_SCODE_STO_PLL	This code identifies the State observer + PLL sensor
UI_SCODE_STO_CR	This code identifies the State observer + CORDIC sensor

Table 32. User interface configuration - CFG bit descriptions

Code	Description
UI_CFGOPT_NONE	Enable this option when no other option is selected
UI_CFGOPT_FW	Enable this option when the flux weakening is enabled in the MC firmware
UI_CFGOPT_SPEED_KD	Enable this option when the speed controller has derivative action
UI_CFGOPT_Iq_KD	Enable this option when the Iq controller has derivative action
UI_CFGOPT_Id_KD	Enable this option when the Id controller has derivative action
UI_CFGOPT_DAC	Enable this option if a DAC object is associated with the UI
UI_CFGOPT_SETIDINSPDMODE	Enable this option to allow setting the Id reference when MC is in speed mode
UI_CFGOPT_PLLTUNING	Enable this option to allow setting the PLL KP and KI

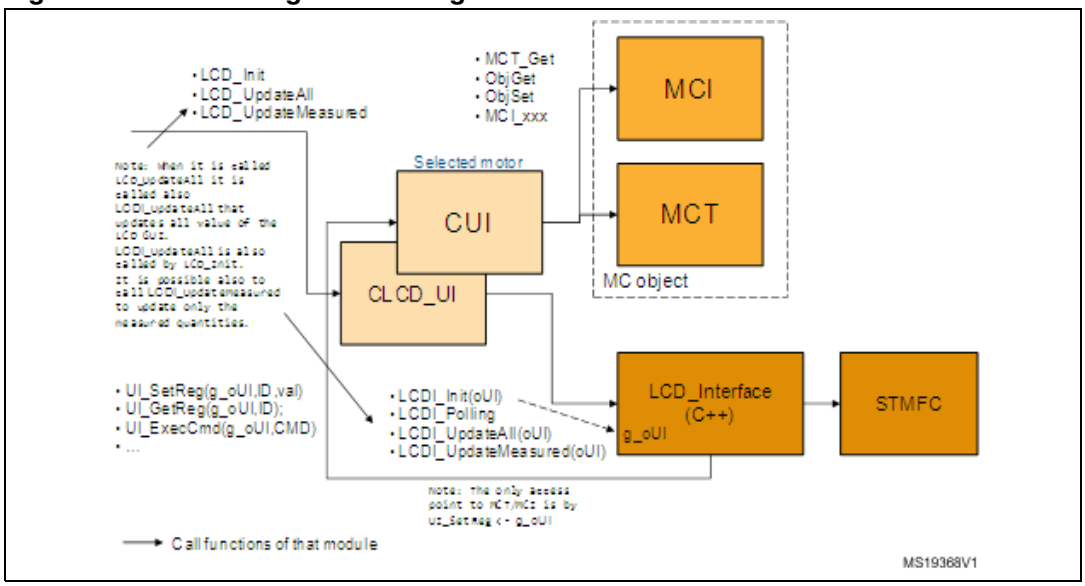
9.3 LCD manager class (CLCD_UI)

This is a derived class of UI that implements the management of the LCD screen. It is based on the LCD graphical library STMFC written in C++ language.

A functional block diagram of LCD manager is shown in *Figure 76*.

The MC objects (MCI/MCT) are linked to the LCD manager by the UI_Init and are accessed only by base class methods.

Figure 76. LCD Manager block diagram



The LCD_Interface is a module written in C++ that performs the interface between UI objects and the STMFC library.

When LCD_Init or LCD_UpdateAll are called, the LCDI_UpdateAll method is also called and updates all values of the LCD GUI. You can also call LCDI_UpdateMesured to update only the measured quantity (the quantity that changes inside the MC object itself such as measured speed, measure I_q).

9.4 Using the LCD Manager

To use the LCD manager, you must:

1. Obtain the oMCT and oMCI object through GetMCIList, GetMCTList functions, exported by MCTasks.h. The oMCI and oMCT are two arrays of objects.

```
CMCI oMCI[MC_NUM];
CMCT oMCT[MC_NUM];
...
GetMCIList(oMCI);
GeMCTList(oMCT);
...
```

2. Instantiate and initialize a CLCD_UI object.

```
CLCD_UI oLCD = LCD_NewObject(MC_NULL);
UI_Init((CUI)oLCD, MC_NUM, oMCI, oMCT, pUICfg);
LCD_Init(oLCD, (CUI)oDAC, s_fwVer);
```

Note that you must call both UI_Init and LCD_Init. LCD_Init must be called after the UI_Init.

   – pUICfg is the user interface configurations array. See *Section 9.2: User interface configuration*.

- oDAC is the related DAC object that should be driven by LCD manager. This DAC object should be correctly instantiated before the LCD_Init calls. See DAC manager class (CDAC).
- s_fwVer is a string that will be displayed in the LCD (See *Figure 63: STM32 Motor Control demonstration project welcome message*) containing both the Firmware version and Release version, it must be separated by the 0x0 character.

3. Periodically call the LCD_UpdateMeasured method. This updates LCD GUI variables and calls the LCD_Exec method that performs the LCD screen refresh.

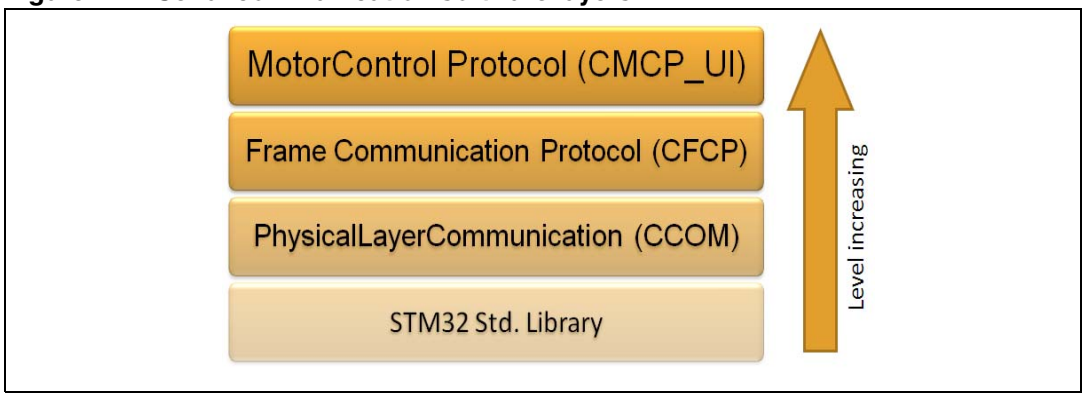
```
LCD_Exec(oLCD);
LCD_UpdateMeasured(oLCD);
```

These functions are performed inside UITask.c. The LCD refresh also uses Timebase.c or RTOS.

9.5 Motor control protocol class (CMCP_UI)

This is a derived class of UI that is based on the serial communication. This class is on the top layer of the serial communication architecture (See *Figure 77*) and manages the highest level of the motor control protocol.

Figure 77. Serial communication software layers



The frame communication protocol (CFCP) implements the transport layer of the serial communication. It is responsible for the correct transfer of the information, CRC checksum and so on.

The class CCOM implements the physical layer, through its derivatives. For each physical communication channel there is a specific derivative of the CCOM object. Only the USART channel has been implemented so far (by CUSART_COM class).

9.6 Using the motor control protocol

1. Obtain the oMCT and oMCI object through GetMCIList, GetMCTList functions, exported by MCTasks.h. The oMCI and oMCT are two arrays of objects.

```
CMCI oMCI[MC_NUM];
CMCT oMCT[MC_NUM];
...
GetMCIList(oMCI);
GeMCTList(oMCT);
...
```

2. MCP parameters, Frame parameters and USART parameters are defined in USARTParams.h and can be modified if required.
3. Instantiate and initialize CMCP_UI, CFCP, COM objects.

```
CMCP_UI oMCP = MCP_NewObject(MC_NULL,&MCPParams);
CFCP oFCP = FCP_NewObject(&FrameParams_str);
CUSART_COM oUSART = USART_NewObject(&USARTParams_str);

FCP_Init(oFCP, (CCOM)oUSART);
MCP_Init(oMCP, oFCP, s_fwVer);
UI_Init((CUI)oMCP, bMCNum, oMCIList, oMCTList, pUICfg);
```

   Note that you must call both MCP_Init and UI_Init.
   - pUICfg is the user interface configurations array. See *Section 9.2: User interface configuration*.
   - s_fwVer is a string containing the Firmware version and Release version. It is separated by the 0x0 character that will be sent back to PC after a "get firmware info" command.
4. Manage the serial communication time out. After the first byte is received by the microcontroller, a timeout timer is started. If all the expected bytes of the frame sequence are received, the timeout counter is stopped. On the contrary if the timeout occurs, the timeout event must be handled calling:

```
Exec_UI_IRQ_Handler(UI_IRQ_USART,3,0);
```

   These functions are performed inside UITask.c. Time base for serial communication time out also uses Timebase.c or RTOS, by default.

9.7 DAC Manager Class (CDACx_UI)

There are three derivatives of CUI that implement DAC management:

- DAC_UI (DAC_UI): DAC peripheral used as output.
- DACRCTIMER_UI (DACT_UI): General purpose timer used and output together with a RC filter.
- DACSPI_UI (DACS_UI): SPI peripheral used as output. The data can be d codified by an oscilloscope for instance.

For each DAC class the number of channels (two) is defined. The DAC variables are predefined motor control variables or user defined variables that can be output by DAC

objects. DAC variables can be any value MC_PROTOCOL_REG_xxx exported by UserInterfaceClass.h. *Table 33* describes a set of relevant motor control quantities.

Table 33. Description of relevant DAC variables

Variable name	Description
MC_PROTOCOL_REG_I_A	Measured phase A motor current.
MC_PROTOCOL_REG_I_B	Measured phase B motor current.
MC_PROTOCOL_REG_I_ALPHA	Measured alpha component of motor phase's current expressed in alpha/beta reference.
MC_PROTOCOL_REG_I_BETA	Measured beta component of motor phase's current expressed in alpha/beta reference.
MC_PROTOCOL_REG_I_Q	Measured "q" component of motor phase's current expressed in q/d reference.
MC_PROTOCOL_REG_I_D	Measured "d" component of motor phase's current expressed in q/d reference.
MC_PROTOCOL_REG_I_Q_REF	Target "q" component of motor phase's current expressed in q/d reference.
MC_PROTOCOL_REG_I_D_REF	Target "d" component of motor phase's current expressed in q/d reference.
MC_PROTOCOL_REG_V_Q	Forced "q" component of motor phase's voltage expressed in q/d reference.
MC_PROTOCOL_REG_V_D	Forced "d" component of motor phase's voltage expressed in q/d reference.
MC_PROTOCOL_REG_V_ALPHA	Forced alpha component of motor phase's voltage expressed in alpha/beta reference.
MC_PROTOCOL_REG_V_BETA	Forced beta component of motor phase's voltage expressed in alpha/beta reference.
MC_PROTOCOL_REG_MEAS_EL_ANGLE	Measured motor electrical angle. This variable is related to "real" sensor (encoder, Hall) configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_MEAS_ROT_SPEED	Measured motor speed. This variable is related to "real" sensor (encoder, Hall) configured as primary or auxiliary speed.
MC_PROTOCOL_REG_OBS_EL_ANGLE	Observed motor electrical angle. This variable is related to "state observer + PLL" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_OBS_ROT_SPEED	Observed motor speed. This variable is related to "state observer+ PLL" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_OBS_I_ALPHA	Observed alpha component of motor phase's current expressed in alpha/beta reference. This variable is related to "state observer + PLL" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_OBS_I_BETA	Observed beta component of motor phase's current expressed in alpha/beta reference. This variable is related to "state observer + PLL" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_OBS_BEMF_ALPHA	Observed alpha component of motor BEMF expressed in alpha/beta reference. This variable is related to "state observer + PLL" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_OBS_BEMF_BETA	Observed beta component of motor BEMF expressed in alpha/beta reference. This variable is related to "state observer + PLL" sensor configured as primary or auxiliary speed sensor.

Table 33. Description of relevant DAC variables (continued)

Variable name	Description
MC_PROTOCOL_REG_OBS_CR_EL_ANGLE	Observed motor electrical angle. This variable is related to "state observer + CORDIC" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_OBS_CR_ROT_SPEED	Observed motor speed. This variable is related to "state observer+ CORDIC" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_OBS_CR_I_ALPHA	Observed alpha component of motor phase's current expressed in alpha/beta reference. This variable is related to "state observer + CORDIC" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_OBS_CR_I_BETA	Observed beta component of motor phase's current expressed in alpha/beta reference. This variable is related to "state observer + CORDIC" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_OBS_CR_BEMF_ALPHA	Observed alpha component of motor BEMF expressed in alpha/beta reference. This variable is related to "state observer + CORDIC" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_OBS_CR_BEMF_BETA	Observed beta component of motor BEMF expressed in alpha/beta reference. This variable is related to "state observer + CORDIC" sensor configured as primary or auxiliary speed sensor.
MC_PROTOCOL_REG_DAC_USER1	User defined DAC variable. *Section 9.9* describes how to configure user defined DAC variables.
MC_PROTOCOL_REG_DAC_USER2	User defined DAC variable. *Section 9.9* describes how to configure user defined DAC variables.

Each DAC variable can be selected to be output to a DAC channel. The DAC channel is physically put in the output by calling the UI_DACExec method.

9.8 Using the DAC manager

1. Obtain the oMCT and oMCI object through GetMCIList, GetMCTList functions, exported by MCTasks.h. The oMCI and oMCT are two arrays of objects.

```
CMCI oMCI[MC_NUM];
CMCT oMCT[MC_NUM];
...
GetMCIList(oMCI);
GeMCTList(oMCT);
...
```

2. Instantiate and initialize CDACx_UI objects. Choose the correct CDACx_UI object based on the hardware setting.

```
CDACx_UI oDAC = DACT_NewObject(MC_NULL,MC_NULL);
UI_Init((CUI)oDAC, bMCNum, oMCIList, oMCTList, pUICfg);
UI_DACInit((CUI)oDAC);
```

   Note that you must call both the UI_Init and UI_DACInit.

   pUICfg is the user interface configurations array. See *Section 9.2: User interface configuration*.

3. Configure the DAC variables for each DAC channel.

```
UI_DACChannelConfig((CUI)oDAC, DAC_CH0, MC_PROTOCOL_REG_I_A);
UI_DACChannelConfig((CUI)oDAC, DAC_CH1, MC_PROTOCOL_REG_I_B);
```

In this case the motor current Ia and Ib will be put in output.

4. Periodically update the DAC output by calling the UI_DACExec method that performs the update of DAC channel into the physical output.

These functions are performed inside UITask.c. For the update the DAC outputs also uses the stm32f10x_MC_it.c.

9.9 How to configure the user defined DAC variables

Two user-defined DAC variables can be put as analog output. These variables enable custom debugging on variables that change in real-time, and monitor the correlation with relevant motor control values such as real/measured currents. You cannot put more than two DAC variables (motor control predefined or user-defined) in the output.

To store the user value in a user-defined DAC variable follow these steps:

1. Obtain the DAC objects oDAC through the GetDAC function exported by UITask.h.
2. Call the UI_DACSetUserChannelValue method of CUI object to update the content of user defined DAC variable.

   ```
   UI_DACSetUserChannelValue(oDAC,0,hUser1);
   ```

   In this case, the value hUser1 is set in the first (0) user defined DAC variable.
3. Configure user-defined DAC variables to be put in output using the UI_DACChannelConfig method or put the user defined variables in the output using the LCD/Joystick interface (see *Section 8.2.3: Configuration and debug page*).

   ```
   UI_DACChannelConfig((CUI)oDAC, DAC_CH0,
   MC_PROTOCOL_REG_DAC_USER1);
   ```
4. The user value is physically put in the output when UI_DACExec is executed.

   The UITask.c performs the following:

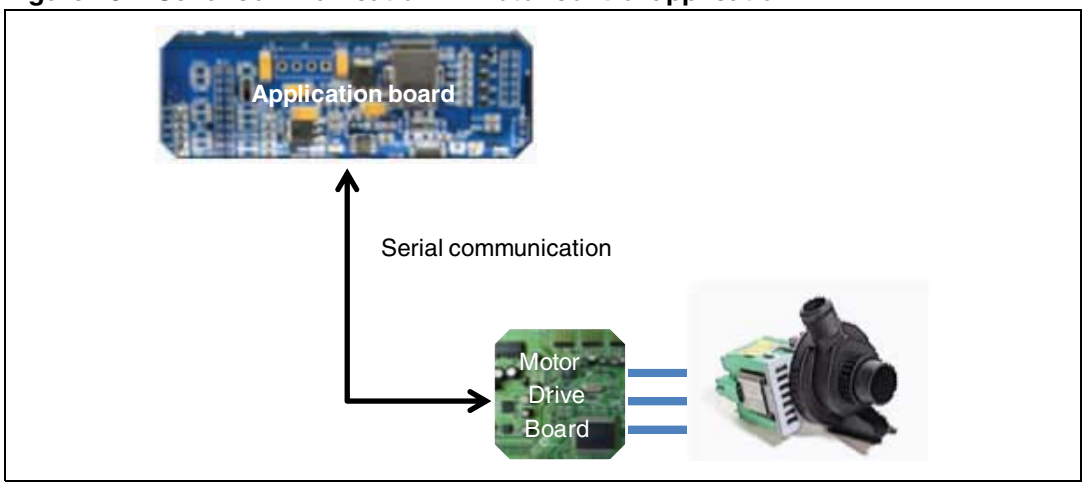
   ```
   UI_DACExec((CUI)oDAC);
   ```

10 Serial communication class overview

Applications on the market that require an electrical motor to be driven usually have the electronics split in two parts: application board and motor drive board.

To drive the system correctly, the application board requires a method to send a command to the motor drive board and get feedback from it. This is usually performed using serial communication. See *Figure 78*.

Figure 78. Serial communication in motor control application



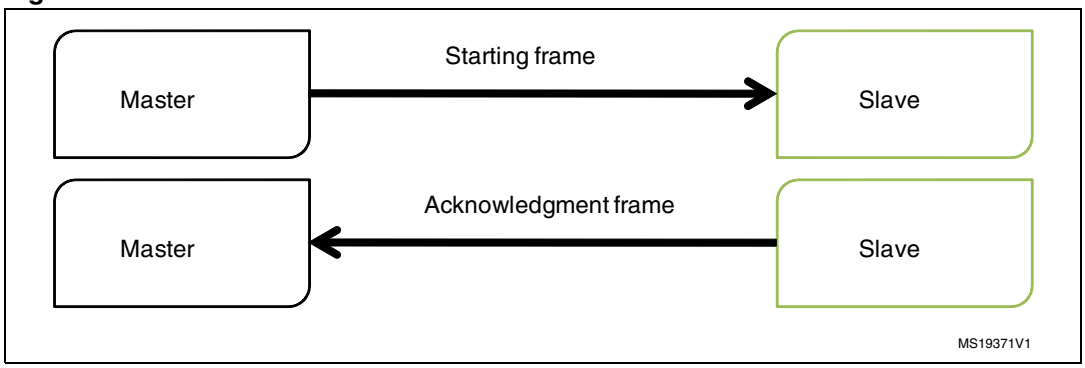
To target this kind of application, a dedicated serial communication protocol has been developed for real-time data exchange. The aim of this protocol is to implement the feature requested by motor control related applications. The implemented protocol is called motor control protocol (MCP).

MCP makes it possible to send commands such as start/stop motor and set the target speed to the STM32 FOC motor control firmware and also to tune in real-time relevant control variables such as PI coefficients. It is also possible to monitor relevant quantities, such as the speed of the motor or the bus voltage present in the board related to the controlled system.

The implemented communication protocol is based on a master-slave architecture in which the motor control firmware running on STM32 microcontroller is the slave.

The master, usually a PC or another microcontroller present on a master board, can start the communication at any time by sending the first communication frame to the slave. The slave answers this frame with the acknowledge frame. See *Figure 79*.

Figure 79. Master-Slave communication architecture



The implemented MCP is based on the physical layer that uses the USART communication.

A generic starting frame (*Table 34*) is composed of:

- Frame_ID: this byte defines the type of the starting frame (See *Table 35*)
- Payload_Length: the total number of bytes that compose the frame payload
- Payload_ID: first byte of the payload that contains the identifier of payload. Not necessary if not required by this type of frame.
- Payload[x]: the remaining payload content. Not necessary if not required by this type of frame.
- CRC: byte used for cyclic redundancy check.

The CRC byte is computed as follows:

$$Total = (unsigned16bit)\left(FrameID + PayloadLength + \Sigma_{i=0}^{n} Payload[i]\right)$$

$$CRC = (unsigned8bit)(HighByte(Total) + LowByte(Total))$$

Table 34. Generic starting frame

FRAME_ID	PAYLOAD_LENGTH	PAYLOAD_ID	PAYLOAD[0]	...	PAYLOAD[n]	CRC

Table 35 shows the list of possible starting frames.

Table 35. Starting frame codes

Frame_ID	Description
0x01	Set register frame. It is used to write a value into a relevant motor control variable. See Set register frame.
0x02	Get register frame. It is used to read a value from a relevant motor control variable. See Get register frame.
0x03	Execute command frame. It is used to send a command to the motor control object. See Execute command frame.
0x06	Get board info. It is used to retrieve the information about the firmware currently running on the microcontroller.
0x07	Exec ramp. It is used to execute a speed ramp. See *Section 10.4: Execute ramp frame*.
0x08	Get revup data. It is used to retrieve the revup parameters. See *Section 10.5: Get revup data frame*.

Table 35. Starting frame codes (continued)

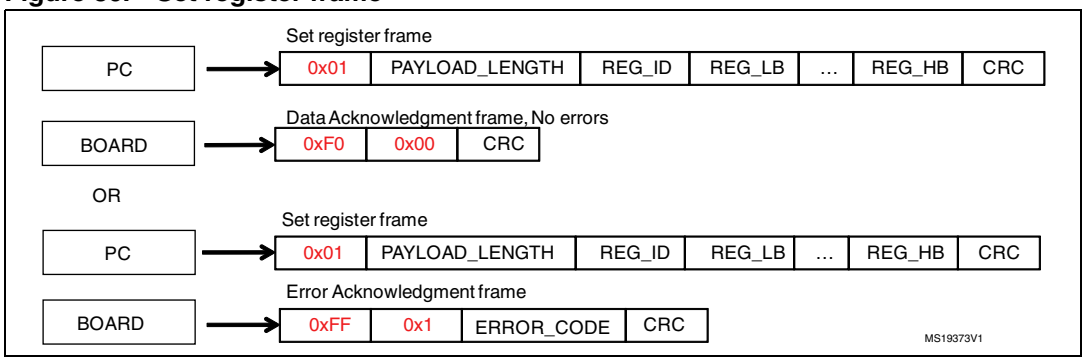
Frame_ID	Description
0x09	Set revup data. It is used to set the revup parameters. See *Section 10.6: Set revup data frame*.
0x0A	Set current references. It is used to set current reference. See *Section 10.7: Set current references frame*

Note: In case of dual motor control, the target of the frame action is only the active motor drive. The master can select the target motor sending a set register frame with a Reg Id equal to zero (Target motor register) and the value of new selected motor (See Section 10.1).

10.1 Set register frame

The set register frame (*Figure 80*) is sent by the master to write a value into a relevant motor control variable.

Figure 80. Set register frame



Payload length depends on REG_ID (See *Table 36*).

Reg Id indicates the register to be updated.

The remaining payload contains the value to be updated, starting from least significant byte to most significant byte.

The Acknowledgment frame can be of two types:

- Data Acknowledgment frame, if the operation has been successfully completed. The payload of this Data Acknowledgment frame is zero.
- Error Acknowledgment frame, if the operation has not been successfully completed by the firmware. The payload of this Error Acknowledgment frame is always 1. The list of error codes are shown in *Table 36*.

Table 36. List of error codes

Error code	Description
0x01	BAD Frame ID. The Frame ID has not been recognized by the firmware.
0x02	Write on read only. Master wants to write on a read only register.
0x03	Read not allowed. The value can't be read.

Table 36. List of error codes (continued)

Error code	Description
0x04	Bad target drive. Target motor is not supported by the firmware.
0x05	Out of range. The value used in the frame is outside the range expected by the firmware.
0x07	Bad command ID. The command ID has not been recognized.
0x08	Overrun error. The frame has not been received correctly because the transmission speed is too fast.
0x09	Timeout error. The frame has not been received correctly and a time out occurs. This kind of error occurs usually when the frame is not correct or is not correctly recognized by the firmware.

Table 37 indicates the following for each of the relevant motor control registers:

- Type (u8 8-bit unsigned, u16 16-bit unsigned, u32 32-bit unsigned, s16 16-bit signed, s32 32-bit signed)
- Payload length in Set register frame
- allowed access (R read, W write)
- Reg Id

Table 37. List of relevant motor control registers

Register name	Type	Payload length	Access	Reg Id
Target motor	u8	2	RW	0x00
Flags	u32	5	R	0x01
Status	u8	2	R	0x02
Control mode	u8	2	RW	0x03
Speed reference	s32	5	RW	0x04
Speed KP	u16	3	RW	0x05
Speed KI	u16	3	RW	0x06
Speed KD	u16	3	RW	0x07
Torque reference (Iq)	s16	3	RW	0x08
Torque KP	u16	3	RW	0x09
Torque KI	u16	3	RW	0x0A
Torque KD	u16	3	RW	0x0B
Flux reference (Id)	s16	3	RW	0x0C
Flux KP	u16	3	RW	0x1D
Flux KI	u16	3	RW	0x1E
Flux KD	u16	3	RW	0x1F
Observer C1	s32	5	RW	0x10
Observer C2	s32	5	RW	0x11

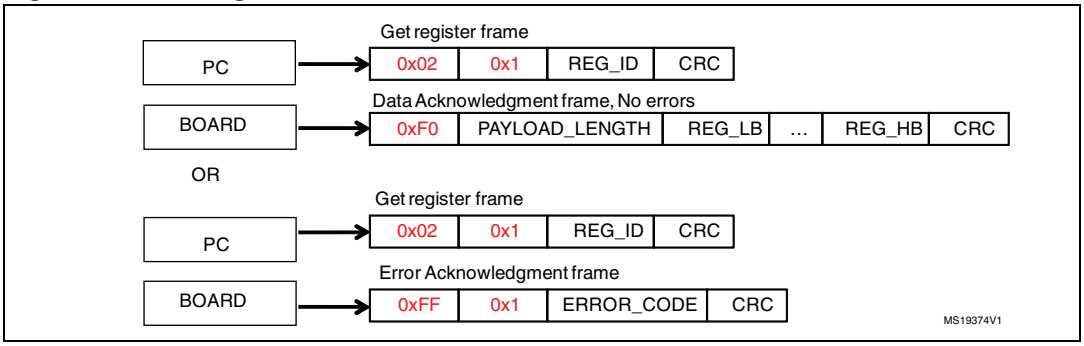
Table 37. List of relevant motor control registers (continued)

Register name	Type	Payload length	Access	Reg Id
PLL KI	u16	3	RW	0x12
PLL KP	u16	3	RW	0x13
Flux weakening KP	u16	3	RW	0x14
Flux weakening KI	u16	3	RW	0x15
Flux weakening BUS Voltage allowed percentage reference	u16	3	RW	0x16
Bus Voltage	u16	3	R	0x17
Heatsink Temperature	u16	3	R	0x18
Motor Power	u16	3	R	0x19
DAC Out 1	u8	2	RW	0x1A
DAC Out 2	u8	2	RW	0x1B
Speed measured	s32	5	R	0x1C
Torque measured (Iq)	s16	3	R	0x1D
Flux measured (Id)	s16	3	R	0x1E
Flux weakening BUS Voltage allowed percentage measured	u16	3	R	0x1F
Revup stage numbers	u8	2	0x20	0x20

10.2 Get register frame

The get register frame (*Figure 81*) is sent by the master to read a value from a relevant motor control variable.

Figure 81. Get register frame



Payload length is always 1.

Reg Id indicates the register to be queried (See *Table 37*).

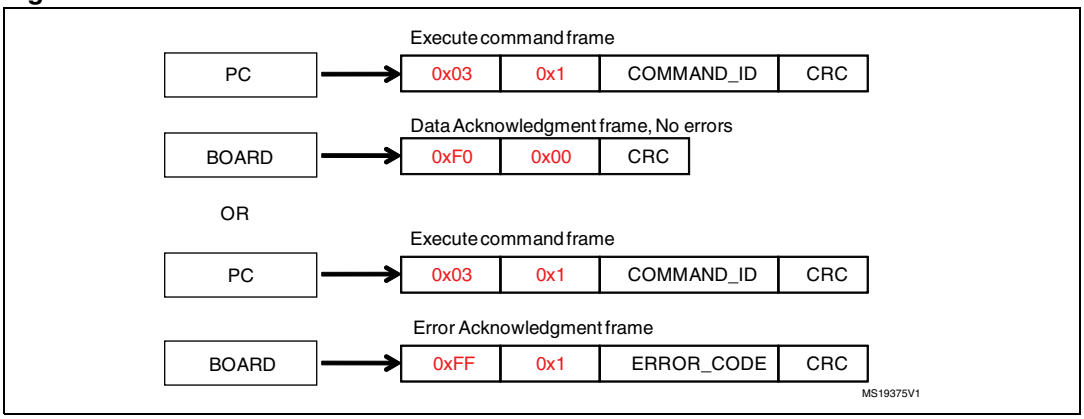
The Acknowledgment frame can be of two types:

- Data Acknowledgment frame, if the operation has been successfully completed. In this case the returned value is embedded in the Data Acknowledgment frame. The size of pay load depends on the Reg Id and is equal to the Payload length present in *Table 37* minus 1. The value is returned starting from least significant byte to most significant byte.
- Error Acknowledgment frame, if the operation has not been successfully completed by the firmware. The payload of this Error Acknowledgment frame is always 1. The list of error codes are shown in *Table 36*.

10.3 Execute command frame

The execute command frame (*Figure 82*) is sent by the master to the motor control firmware to request the execution of a specific command.

Figure 82. Execute command frame



Payload length is always 1.

Command Id indicates the requested command (See *Table 38*).

The Acknowledgment frame can be of two types:

- Data Acknowledgment frame, if the operation has been successfully completed. In this case the returned value embedded in the Data Acknowledgment frame is an echo of the same Command Id. The size of payload is always 1.
- Error Acknowledgment frame, if the operation has not been successfully completed by the firmware. The payload of this Error Acknowledgment frame is always 1. The list of error codes are shown in *Table 36*.

Table 38 indicates the list of the commands:

Table 38. List of commands

Command	Command ID	Description
Start Motor	0x01	Indicates the user request to start the motor regardless the state of the motor.
Stop Motor	0x02	Indicates the user request to stop the motor regardless the state of the motor.

Table 38. List of commands (continued)

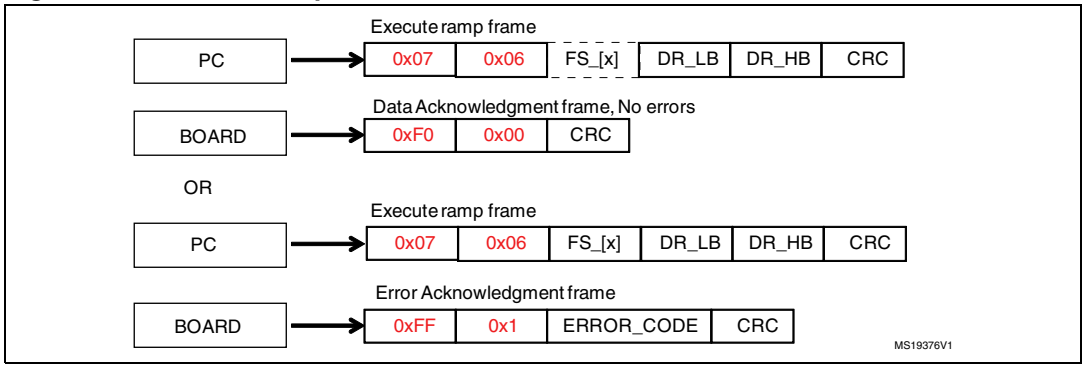
Command	Command ID	Description
Stop Ramp	0x03	Indicates the user request to stop the execution of speed ramp that is currently executed
Start/Stop	0x06	Indicates the user request to start the motor if the motor is still or stop the motor is runs.
Fault Ack	0x07	Communicates the user acknowledges of the occurred fault conditions.
Encoder Align	0x08	Indicates the user request to perform the encoder alignment procedure.

10.4 Execute ramp frame

The execute ramp frame (*Figure 83*) is sent by the master to the motor control firmware to request the execution of a speed ramps.

A speed ramps start always from the current motor speed, and is defined by a duration and final speed. See *Figure 84*.

Figure 83. Execute ramp frame



Payload length is always 6.

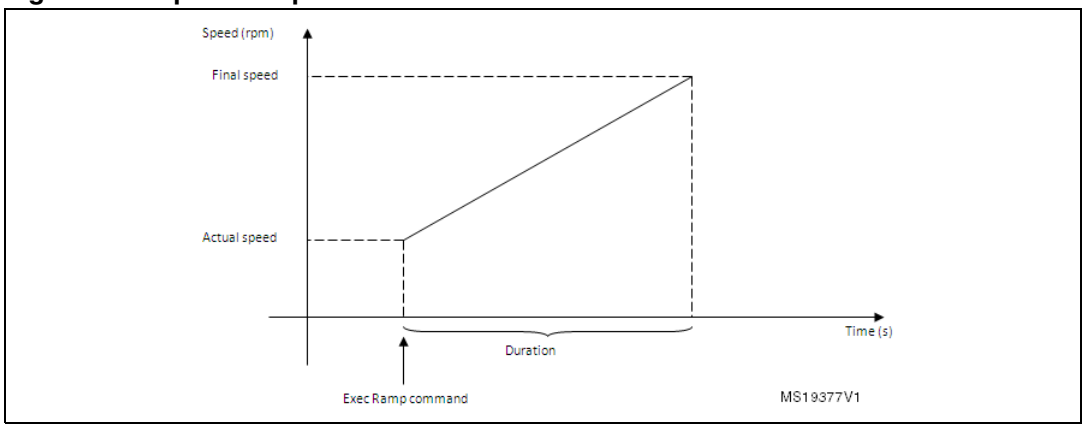
The four bytes FS[x] represent the final speed expressed in rpm least significant byte and most significant byte.

DR_LB and DR_HB represent the duration expressed in milliseconds respectively least significant byte and most significant byte.

The Acknowledgment frame can be of two types:

- Data Acknowledgment frame, if the operation has been successfully completed, the payload of this Data Acknowledgment frame will be zero
- Error Acknowledgment frame, if the operation has not been successfully completed by the firmware. The payload of this Error Acknowledgment frame is always 1. The list of error codes are shown in *Table 36: List of error codes*.

Figure 84. Speed ramp

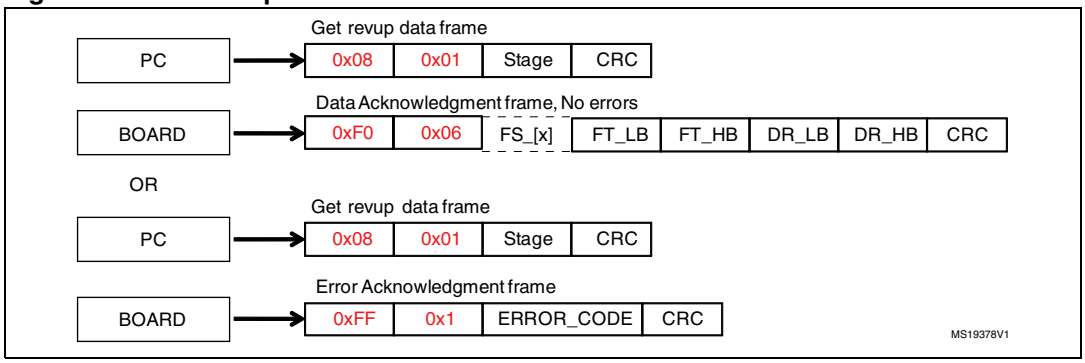


10.5 Get revup data frame

The get revup data frame (*Figure 85*) is sent by the master to retrieve the current revup parameters.

Revup sequence is a set of commands performed by the motor control firmware to drive the motor from zero speed up to run condition. It is mandatory for sensorless configuration. The sequence is split into several stages, and a duration, final speed and final torque (actually I_q reference) can be set up for each stage. See *Figure 86*.

Figure 85. Get revup data frame



The master indicates the requested stage parameter sending the stage number in the starting frame payload. Payload length is always 1.

The Acknowledgment frame can be of two types:

- Data Acknowledgment frame, if the operation has been successfully completed. In this case the returned values are embedded in the Data Acknowledgment frame. The pay load size of this Data Acknowledgment frame is always 8.

  The four bytes FS[x] represent the final speed of the selected stage expressed in rpm from least significant byte to most significant byte.

  FT_LB and FT_HB represent the final torque of the selected stage expressed in digit respectively least significant byte and most significant byte.

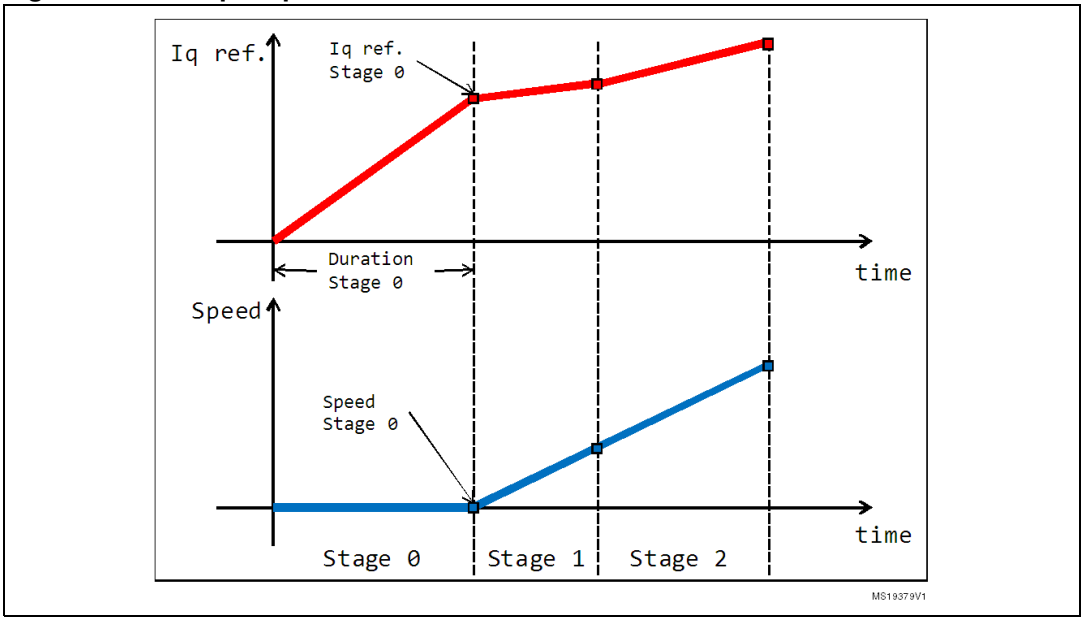
Note: To convert current expressed in Amps to current expressed in digit, use the formula:

Current(digit)=[Current(Amp)×65536×R_Shunt×A_OP]/V_(DD Micro)

DR_LB and DR_HB represent the duration of the selected stage expressed in milliseconds respectively least significant byte and most significant byte.

- Error Acknowledgment frame, if the operation has not been successfully completed by the firmware. The payload of this Error Acknowledgment frame is always 1. The list of error codes are shown in *Table 36: List of error codes*.

Figure 86. Revup sequence

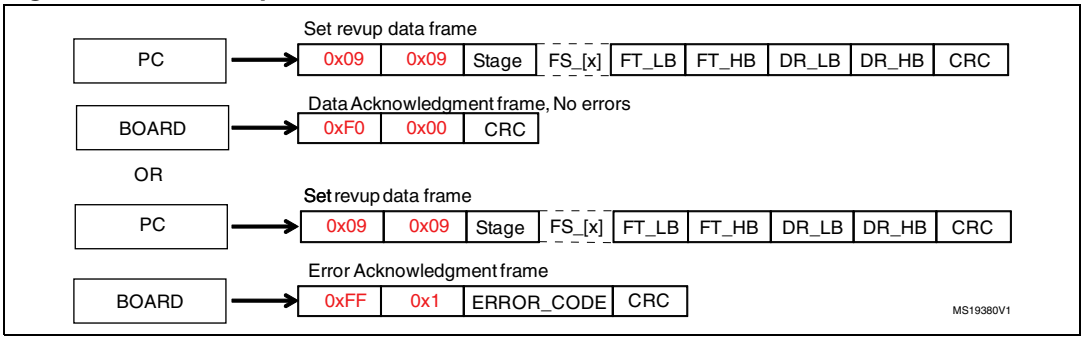


10.6 Set revup data frame

The set revup data frame (*Figure 87*) is sent by the master to modify the revup parameters.

Revup sequence is a set of commands performed by the motor control firmware to drive the motor from zero speed up to run condition. It is mandatory for sensorless configuration. The sequence is split into several stages. For each stage a duration, final speed and final torque (actually I_q reference) can be set up. See *Figure 86*.

Figure 87. Set revup data frame



The Master sends the requested stage parameter.

The payload length is always 9.

Stage is the revup stage that will be modified.

The four bytes FS[x] is the requested new final speed of the selected stage expressed in rpm from the least significant byte to the most significant byte.

FT_LB and FT_HB is the requested new final torque of the selected stage expressed in digit respectively least significant byte and most significant byte.

Note: To convert current expressed in Amps to current expressed in digit is possible to use the formula:

*Current(digit) = [Current(Amp) * 65536 * Rshunt * Aop] / Vdd micro.*

DR_LB and DR_HB is the requested new duration of the selected stage expressed in milliseconds respectively least significant byte and most significant byte.

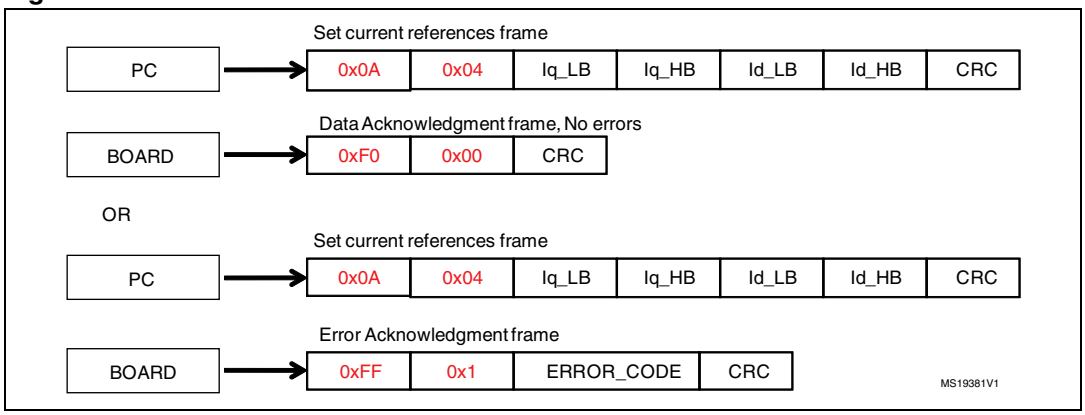
The Acknowledgment frame can be of two types:

- Data Acknowledgment frame, if the operation has been successfully completed, the payload of this Data Acknowledgment frame will be zero.
- Error Acknowledgment frame, if the operation has not been successfully completed by the firmware. The payload of this Error Acknowledgment frame is always 1. The list of error codes are shown in *Table 36*.

10.7 Set current references frame

The set current references frame (*Figure 88*) is sent by the Master to modify the current references I_q, I_d.

Figure 88. Set current reference frame



The Master sends the requested current references.

The payload length is always 4.

Iq_LB and Iq_HB is the requested new Iq reference expressed in digit respectively least significant byte and most significant byte.

Id_LB and Id_HB is the requested new Id reference expressed in digit respectively least significant byte and most significant byte.

Note: To convert current expressed in Amps to current expressed in digit is possible to use the formula:

Current(digit)=[Current(Amp)×65536×R_Shunt×A_OP]/Vdd micro)

The Acknowledgment frame can be of two types:

- Data Acknowledgment frame, if the operation has been successfully completed, the payload of this Data Acknowledgment frame will be zero.
- Error Acknowledgment frame, if the operation has not been successfully completed by the firmware. The payload of this Error Acknowledgment frame is always 1. The list of error codes are shown in *Table 36: List of error codes*.

11 Document conventions

Table 39. List of abbreviations

Abbreviation	Definition
AC	Alternate Current
API	Application Programming Interface
B-EMF	Back Electromotive Force
CORDIC	COordinate Rotation DIgital Computer
DAC	Digital to Analog Converter
DC	Direct Current
FOC	Field Oriented Control
GUI	Graphical User Interface
I-PMSM	Internal Permanent Magnet Synchronous Motor
IC	Integrated Circuit
ICS	Isolated Current Sensor
IDE	Integrated Development Environment
MC	Motor Control
MCI	Motor Control Interface
MCT	Motor Control Tuning
MTPA	Maximum Torque Per Ampere
PID controller	Proportional-Integral-Derivative controller
PLL	Phase-Locked Loop
PMSM	Permanent Magnet Synchronous Motor
SDK	Software Development Kit
SM-PMSM	Surface Mounted Permanent Magnet Synchronous Motor
SV PWM	Space Vector Pulse-Width Modulation
UI	User Interface

Appendix A Additional information

A.1 References

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Revision history

Table 40. Document revision history

Date	Revision	Changes
18-Apr-2011	1	Initial release.
24-May-2011	2	Added references for web and confidential distributions of STM32 FOC PMSM SDK v3.0

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